The association between corticomotor excitability and motor skill learning in people with painful hand arthritis

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Abstract

Objectives: Previous studies have shown a tendency for reduced motor cortex inhibition in chronic pain populations. People with chronic pain also routinely demonstrate motor deficiencies, including skill learning. The goals of the current study were to 1) provide a thorough analysis of corticomotor and intracortical excitability in people with chronic arthritic hand pain, and 2) examine the relationship between these measures and performance on a motor skill learning task. **Methods:** Twenty-three people with arthritic hand pain and 20 pain-free controls participated in a cross-sectional study. Transcranial magnetic stimulation was used to assess corticomotor and intracortical excitability of the first dorsal interosseus muscle. Participants then completed a 30-min motor skill training task involving the index finger of the same hand. **Results:** Hand arthritis participants showed evidence of reduced intracortical inhibition and enhanced facilitation, which correlated with duration of hand pain. Arthritis participants were initially poorer at the motor skill task but over the total training time performance was equivalent between groups. There were no associations found between measures of intracortical excitability and motor skill learning. **Discussion:** Our findings are the first to provide evidence of cortical disinhibition in people with painful arthritis, as previously demonstrated in other chronic pain populations. Cortical excitability changes may progress the longer pain persists, with increased pain duration being associated with greater cortical disinhibition. There was no evidence that these changes in cortical excitability are related to impaired motor function or skill learning.

Key words: arthritis, corticomotor excitability, motor learning, neural plasticity

Introduction

Chronic hand pain is a frequent occurrence in the community, with the prevalence rising to 30% in those aged over 50 years.[1-3] Arthritis is a common cause of hand pain and leads to significantly impaired function[4,5] and reduced quality of life.[1,3] Previous studies have shown that people with hand arthritis have reduced motor control[6] and impaired skill learning.[7] These motor system changes may arise through sensorimotor system reorganisation as a consequence of chronic pain. There is evidence that many chronic pain populations have altered excitability of the primary motor cortex.[8-12] Additionally, it has been observed that the extent of motor cortex reorganisation in chronic pain is correlated with the degree of motor control impairment.[13]

Current evidence suggests that there is a reduction in inhibitory activity in the motor cortex of chronic pain populations.[8,9,11,12,14-16] Neural plasticity that arises during motor skill learning is also associated with a reduction in inhibition within the motor cortex. As the brain has a limited capacity to reorganise,[17] it may be theorised that chronic pain patients do not have the same capacity for learning-induced plasticity because motor cortex inhibition is already reduced. In support of this, Lefaucheur and colleagues[18] found that people with chronic pain responded differently to interventions aimed at altering cortical excitability. That is, a brain stimulation intervention that normally reduces motor cortex inhibition in healthy people resulted in an increase in inhibition in people with neuropathic pain. Paradoxically, experimental pain models have shown that acute pain normally enhances intracortical inhibition and reduces overall corticomotor excitability,[19-22] the opposite to that seen in chronic pain. Acute pain has also been shown to alter motor learning induced neural plasticity and the capacity to acquire novel motor skills.[23-25] Thus, the nature of the relationship among pain, corticomotor excitability, and motor learning is unclear.

To our knowledge, no studies to date have examined corticomotor excitability in people with chronic hand pain and related this to motor learning ability. Therefore, the primary goals of the current study were to 1) determine how chronic arthritic pain affects corticomotor excitability, and 2)

establish if arthritic pain influences the efficacy of motor learning and examine if this relates this to changes in corticomotor excitability. If the findings of this study indicate a relationship between corticomotor excitability and motor learning, they will aid in our understanding of how chronic pain may influence motor learning in this population, and support clinical use of interventions that modulate corticomotor excitability as a means to improve motor control.

Materials and Methods

Participants

Participants were 23 people with painful hand arthritis and 20 controls without hand pain (Table 1). The sample size was based on a power calculation using the results of a previous, similar study investigating corticomotor excitability in people with neuralgia and healthy controls.[12] Inclusion in the arthritis group required hand pain for a minimum of three months, pain of at least 3 out of 10 on the pain numeric rating scale at least every other day for the preceding month, and to have received a previous diagnosis of hand arthritis by a medical doctor. Clinical information on the arthritis group was obtained using the Short-Form McGill Pain Questionnaire II (SFMPQII)[26] and the Australian/Canadian Hand Osteoarthritis Index (AUSCAN).[5] Control participants were required to be without current or previous pain in their upper limbs and were age- and gender-matched to the arthritis group. All participants were required to be at least 18 years old and fluent in English. Participants were excluded if they had known contraindications to transcranial magnetic stimulation (TMS), a neurological condition, a musculoskeletal condition affecting the upper limbs (other than arthritis), a history of chronic pain (other than arthritis), or if they were taking drugs that alter central nervous system excitability. The majority of the participants did not have a history of a specific hand motor activity, with the exception of one person in each group who were piano players. In both groups, approximately half of participants had cardiovascular conditions that were controlled with medication, while 18 of the arthritis group and 8 of the control group had musculoskeletal conditions affecting the trunk or lower limbs. Ethical approval was gained from the

Auckland University of Technology Ethics Committee and informed, voluntary consent was obtained prior to participation.

Procedure

The study was conducted in a University laboratory setting. Participants were asked to refrain from strenuous use of their hands prior to the test session. They were seated in a comfortable chair with the target hand and elbow supported on a pillow. The most painful hand was assessed for the arthritis group and this was matched for handedness in the control group. Throughout the session, participants were encouraged to be as relaxed as possible. Assessments of corticomotor excitability were undertaken first, followed by the motor learning protocol. Due to time constraints, three of the arthritis and three of the control participants undertook the corticomotor excitability and motor learning procedures in two separate sessions separated by 7-10 days.

Electromyography

Electromyographic (EMG) activity in the first dorsal interosseus (FDI) muscle was measured using a Norotrode20^{TM} bipolar Ag/AgCl 22 mm self-adhesive surface electrode (Myotronics Inc, Kent, WA). The FDI was located using palpation and the electrodes placed over the muscle belly. Standard skin preparation techniques were applied to minimise impedance. EMG data were amplified (x 1,000) and filtered (10-1,000 Hz) using an AMT-8 (Bortec Biomedical Ltd, Canada). Data were sampled at 5,000 Hz using a Micro 1401 and Signal software (Cambridge Electronic Design, Cambridge, UK).

Assessment of corticomotor excitability

Corticomotor and intracortical excitability were assessed using single- and paired-pulse TMS with a Bistim module and two Magstim 200^2 stimulators (Magstim Co. Ltd, Dyfed, UK). A 70 mm figure-of-eight coil was used to deliver monophasic stimuli. The coil was placed over the motor cortex contralateral to the target hand at 45° to the sagittal plane to produce a posterior to anterior current. From this position, the coil was systematically moved over the scalp delivering suprathreshold stimuli until the site eliciting the largest motor evoked potential (MEP) in the FDI was

located ("hotspot"). The hotspot was marked with a pen and the remaining stimuli were delivered with the coil located at this position. The average time interval between stimuli was 6 s; this was varied to prevent predictability. To maintain a consistent level of attention during stimulation,[27] participants were asked to count each stimulus and to inform the researcher when they had counted 20, 40, 60 and 80 stimuli. During all assessments at rest, FDI muscle activity was continuously monitored to ensure quiescence.

Resting motor threshold (RTh) was defined as the minimum stimulus intensity that elicited a MEP with a peak-to peak amplitude of at least 50 μV in a minimum of four out of a train of eight stimuli. It was established by increasing stimulus intensity in 5% increments until MEPs were elicited, and then adjusting intensity in 1% intervals until RTh was determined.[28] A stimulus response curve was then obtained by delivering single stimuli at a range of intensities relative to RTh. A total of 80 stimuli were delivered at 10% increments from 90-160% RTh, with 10 stimuli delivered at each intensity. The order of stimuli was randomised for each participant. The peak-to-peak amplitude of each MEP was determined and averaged for each stimulus intensity. To construct the stimulus-response curve, the mean MEP amplitude was plotted against stimulus intensity for each participant. SPSS software V19 (IBM Corp.) was used to fit the data with a Boltzmann equation.[29,30] Using this equation, MEP amplitude at stimulus intensity s is determined by:

$$\text{MEP}s = \text{MEP}_{max} / (1 + \exp((s50 - s) / m))$$

Where MEP_{max} is the maximum MEP amplitude defined by the function, m is a slope parameter ($1/m$ is proportional to the slope), and $s50$ is the stimulus intensity where the MEP size would be 50% of the MEP_{max}.

Short-interval intracortical inhibition (SICI), short-interval intracortical facilitation (SICF), and long-interval intracortical inhibition (LICI) were assessed using paired-pulse stimulation. A block of 60 test stimuli were delivered over the hot spot. Ten stimuli were delivered for each of six conditions,

including two SICI and SICF conditions, one LICI condition, and one single-pulse condition. The stimulus for the single-pulse condition was set to elicit a response of approximately 1 mV in size (TS_{1mV}). For the two assessments of SICI, the conditioning stimulus was set at 70% ($SICI_{70}$) or 80% ($SICI_{80}$) RTh and the test stimulus was TS_{1mV}, with an interstimulus interval of 2 ms.[31] For the two assessments of SICF, the conditioning stimulus was TS_{1mV} and the test stimulus was 90% RTh, with an interstimulus interval of 1.4 ms ($SICF_{1.4}$) or 2.8 ms ($SICF_{2.8}$).[32,33] For the assessment of LICI, the conditioning stimulus was 120% RTh and the test stimulus was TS_{1mV}, with an interstimulus interval of 99 ms.[34,35] Paired-pulse responses were processed by dividing the mean conditioned peak-to-peak MEP amplitude by the mean single-pulse MEP amplitude, such that values <1 reflect MEP inhibition and values >1 reflect MEP facilitation.

The cortical silent period was assessed during a 10% maximum voluntary contraction of FDI. Ten stimuli were delivered at 120% RTh. The duration of the silent period was measured from the MEP onset, when the EMG exceeded the baseline level, until EMG activity reached or exceeded the pre-stimulus baseline level for at least 50 ms.[28]

Assessment of motor learning

The index finger of the target hand was inserted into a custom-made adjustable ring device attached to a 6 degree-of-freedom load cell (67M50A, JR3 Inc, USA). The preferred twitch direction of the index finger was assessed by applying single-pulse TMS over the pre-determined hotspot. Stimulus intensity was adjusted until a consistent, discernible force response was evident in the load cell recordings. Twenty cortical stimuli were delivered at this intensity. For each stimulus, the twitch direction at the peak twitch force within 250 ms post-stimulus was determined and then averaged across the 20 stimuli. This average twitch direction was defined as the baseline twitch direction.

The participants then undertook 30 minutes of motor skill training. This involved voluntary finger twitches to a target direction in response to an auditory cue. The cue was provided randomly every 2-3 seconds. The target training direction was set to 180° from the baseline twitch direction. That is,

participants practiced voluntary finger twitches in the opposite direction to the baseline TMS-induced finger twitches (Figure 1). The target direction was provided on a computer screen and participants received visual real-time feedback on their actual twitch direction and magnitude. Participants were instructed to generate the voluntary finger twitches as quickly as possible in response to the cue. A target twitch magnitude was provided on the screen; however, participants were asked to focus on achieving the appropriate direction. Participants were given a 2-3 min practice prior to the commencement of training.

Preferred stimulation-induced twitch direction was re-assessed using TMS immediately (post 0) and at 10 minutes (post 10) following training. In each time period, 20 magnetic stimuli were delivered over the hotspot at the same intensity as used previously.

In each assessment time period (baseline, post 0, post 10), the number of TMS-induced twitches in the baseline direction ($\pm27.5^o$) and in the training direction ($\pm27.5^o$) were counted. To gauge motor performance during training, the number of voluntary training twitches completed within 500 ms of the auditory cue that were within $\pm27.5^o$ of the training direction were counted and expressed as a percent of the total training twitches undertaken. To provide a measure of skill learning, the training twitches were divided into ten equal epochs and the percent of accurate twitches in the first and last epoch recorded. The difference between these two was determined as a measure of motor learning.

Data Analysis

Continuous and nominal participant characteristics (age, gender, body mass index, hand dominance) were compared between the arthritis and control groups using independent sample *T*-tests and Chi squared tests, respectively. For the assessments of corticomotor excitability, the dependent variables (RTh, stimulus-response curve parameters, SICI, SICF, LICI, and silent period duration) were compared between the two groups using independent sample *T*-tests. A correlational analysis was also performed to determine if there were relationships between the corticomotor excitability measures and clinical characteristics in the arthritis group. To limit the number of correlations

performed, only the corticomotor excitability measures that differed significantly in the arthritis group were included.

For the motor learning data, the overall percent of accurate training twitches, the percent accurate in the 1st and 10th epochs, and the difference in accuracy between the 1st and 10th epochs were compared between the two groups using independent sample T-tests. The percent of stimulation-induced twitches falling within the baseline and training directions were analysed using 2-way ANOVAs with the factors of group (arthritis, control) and time (baseline, post 0, post 10). To determine any relationships between the neurophysiological and behavioural data, correlations were performed between the corticomotor excitability measures that were significantly different in the arthritis group and the motor learning outcome measures.

The data were analysed using SPSS software V19. Statistical significance was set at an alpha-level of 0.05.

Results

There were no significant differences in age, gender, hand dominance, or body mass index between the two groups (all P>0.2). Three of the arthritis participants did not complete the motor learning protocol; a consistent baseline twitch was not able to be elicited in two participants and the third was unable to relax their FDI while in the ring device. Additionally, motor learning data were unable to be analysed from one arthritis and one control participant due to electrical noise in the load cell recordings.

Corticomotor excitability

Stimulus response curves for the two groups are shown in Figure 2, while Table 2 displays summary information for all of the corticomotor excitability outcome measures. There were significant differences in $SICI_{80}$ and $SICF_{1.4}$ between the two groups (both P=0.03), with the arthritis group displaying less $SICI_{80}$ and greater $SICF_{1.4}$ in comparison to the control group. There were no other

significant differences observed in stimulus response, paired pulse, or cortical silent period data (all $P>0.05$).

Correlations with clinical data

Table 3 shows Pearson correlations among the two corticomotor excitability measures that were significantly different in the arthritis group and clinical data. Pain duration had a significant positive correlation with both $SICI_{80}$ ($r = 0.60$) and $SICF_{1.4}$ ($r = 0.48$), indicating reduced SICI and enhanced SICF with a longer pain duration (Figure 5). There were no other significant correlations (all $P>0.05$).

Motor learning

Example motor learning finger twitch data are shown in Figure 3. There was no difference in the number of training twitches performed (arthritis:755±24; control:749±14; $P=0.3$), the magnitude of training twitches (arthritis:3.5±1.5; control:3.8±2.2; $P=0.6$), or in the overall accuracy of training twitches (arthritis:71±21%; control:75±21%; $P=0.6$) between the two groups. However, there were differences in twitch accuracy across the training epochs. The arthritis group (54±30%) had a significantly lower number of accurate voluntary twitches in the first 10% of training trials compared to the control group (72±42%; $P=0.05$). The difference in accuracy in the final 10% of training trials was not significant (arthritis=72±26%; control=72±42%; $P=0.98$); however, the change in accuracy from the 1st to the 10th epoch, reflecting skill learning, was significantly greater for the arthritis group (18±25%) compared to the control group (0±43%; $P=0.02$).

A graph showing the number of TMS-induced twitches in the baseline and training directions is shown in Figure 4. There was a main effect of time for both the baseline ($F_{2,72}=33$; $P<0.001$) and training ($F_{2,72}=5.7$; $P=0.005$) directions but the main effect of group and the interaction effect were not significant (all $P>0.3$). The number of twitches in the baseline zone (Figure 4A) reduced from the baseline assessment to post 0 ($P<0.001$) and remained significantly less than baseline at post 10 ($P<0.001$), reflecting a reduction in the number of TMS-induced twitches in the baseline direction following training. Inversely, the number of twitches in the training direction increased after training

(Figure 4B), although the difference from baseline was not significant until post 10 (P=0.007). This reflects an increase in the number of TMS-induced twitches in the training direction following skill training.

Correlations with corticomotor excitability

Pearson correlations between training twitch accuracy data and corticomotor excitability measures of $SICI_{80}$ and $SICF_{1.4}$ are shown in Table 3. There were no significant correlations detected.

Discussion

This study provides evidence of reduced intracortical inhibition and enhanced intracortical facilitation in people with hand pain due to arthritis. In addition, relationships were observed between pain duration and these measures of intracortical excitability, with increased pain duration associated with less inhibition and more facilitation. People with arthritis showed an impairment in motor performance in the initial stage of a motor skill task; however, against our hypothesis, they demonstrated evidence of greater motor learning during the task in comparison to the control group. We could not find any evidence of an association between skill learning and measures of corticomotor excitability. These findings are discussed in further detail below.

Pain and Corticomotor Excitability

This is the first study to show a relationship between chronic pain and SICF. Patients with arthritic hand pain demonstrated significantly enhanced facilitation at the 1.4 ms interval compared with age-matched controls. Although this facilitatory phenomenon is not fully understood, it is thought to result from interactions between indirect descending volleys (I-waves) at an intracortical level.[32,36,37] The first I-wave results from stimulation of the axons of excitatory interneurons which synapse on to corticospinal neurons, while the subsequent I-waves are generated by local polysynaptic interneuronal circuits.[32] Enhanced SICF suggests increased excitability of these interneuronal circuits. The likely involvement of a subcortical contribution to later I-waves[38] may explain why significantly enhanced facilitation was present only at the 1.4 ms interval. Evidence also indicates that SICF is

modulated by GABA$_A$ inhibition,[32,36] so a contribution from reduced cortical inhibitory processes cannot be discounted. Only one previous study has examined the effects of chronic pain on SICF. While Eisenberg et al.[8] found that SICF was not significantly altered in people with upper limb complex regional pain syndrome (CRPS), they did observe enhanced facilitation in the hemisphere associated with the painful limb compared with the contralateral side.

SICI$_{80}$ was also impaired in our arthritis group. SICI is thought to result from activation of GABA$_A$-mediated intracortical inhibitory interneurons.[36,39,40] Overall, chronic pain tends to be associated with a reduction in SICI,[8,9,11,12,14,15,41] although previous studies involving people with arthritis have failed to find evidence of motor cortex disinhibition.[12,42] We report reduced SICI with a conditioning intensity of 80% RTh but not 70%. It is known that SICF can contaminate measurements of SICI, particularly when using higher conditioning stimulus intensities.[43] Thus, while supporting the notion of disinhibition in people with chronic pain, heightened SICF circuits may make a substantial contribution to this finding. SICI should be investigated in detail in the chronic pain population using a range of conditioning stimulus intensities to more clearly elucidate the circuits involved.

The effects of chronic pain on LICI have been less comprehensively examined. Similar to two previous studies that investigated people with migraine[44] and CRPS,[8] we did not find any significant alterations in LICI. The circuits mediating LICI are distinct from those that mediate SICI and SICF, with transmission occurring via GABA$_B$ receptors.[45-47] The silent period is also purported to be predominantly mediated by GABA$_B$ inhibitory circuits[28] and we also found no differences in this measure between the arthritis and control groups. This is in accordance with some previous studies investigating the silent period in people with chronic pain.[14,48-50] However, other studies suggest there is a reduction in the silent period in chronic pain,[9] including the only other previous study to investigate the measure in people with arthritis.[51] Again, while there is a tendency for reduced GABA$_B$ inhibition in the chronic pain population, it does not appear to be a consistent finding.

The current study found no significant differences in RTh or any of the measures relating to the stimulus-response curve, suggesting that hand arthritis pain is not associated with a change in the overall excitability or synaptic efficacy of the corticospinal pathway. This follows the majority of previous studies that have observed no significant differences between participants with pain and healthy controls in these outcomes.[8,9,11,12,52] This may be a consequence of the non-specific nature of the corticospinal measures, which are influenced by both spinal and cortical level processes.

Correlations between Corticomotor Excitability and Pain

Moderate associations were observed between measures of intracortical excitability and the clinical symptom duration. The relationships are consistent with the notion that intracortical changes progress the longer pain persists, which may account for some of the variance in previous findings regarding measures of intracortical excitability and chronic pain. Previous studies have shown relationships between pain intensity measures and SICI,[12] silent period duration,[9] and RTh[42] in chronic pain populations. We did not detect any significant correlations between the intracortical excitability measures and pain intensity, as measured by the SFMPQII, suggesting that pain duration rather than pain intensity may be more important in the hand arthritis population. Longitudinal studies are required to determine whether such corticomotor changes contribute to the disease process or if they are an adaptation arising from long-term pain.

Motor learning

Motor control deficits and reduced function are commonly observed in the arthritis population.[1,6,53,54] In the current study, performance of the motor skill task was not diminished overall in the arthritis group, but they had poorer performance initially and then improved with training. Thus, contrary to our initial hypothesis, the arthritis group demonstrated evidence of greater motor learning compared to the control group. Evidence of neural plasticity associated with training was present in the stimulation-induced twitch data. In both groups, there were fewer twitches in the baseline direction and more in the training direction after the training period. These

data show training-induced reorganisation occurring in the motor cortex that was not different between groups.

Lefaucheur et al.[9] found that people with chronic neuropathic pain responded differently to brain stimulation interventions that normally inhibit or excite cortical excitability, and suggested this may be due to their impaired baseline intracortical inhibition. From this result, it could be speculated that people with chronic pain would not have the same capacity for learning-induced cortical reorganisation as cortical inhibition is already reduced. In support of this hypothesis, Vallence et al.[7] provided evidence of diminished motor learning in a hand task performed by a population with chronic headache. Despite these findings, our results provide no evidence of impaired learning in the arthritis group or any association between intracortical excitability measures and motor performance or learning outcomes. Therefore, we are unable to provide any further information on a possible relationship between altered corticomotor excitability and motor learning in chronic pain conditions. There is the potential that both enhanced and reduced intracortical inhibition can influence motor control and learning, obscuring the outcomes of correlational analyses. Indeed, cortical disinhibition in the arthritis group in our study may well have facilitated rapid learning in the motor training task. Further studies are obviously required to determine if altered intracortical excitability in populations with chronic pain impacts motor control and learning.

Limitations

Some patients had pain associated with musculoskeletal conditions in the trunk and lower limbs. This is not unusual in a cohort of this age. More importantly, the level of pain in these conditions was low, presented irregularly, and did not have the characteristics indicative of chronic pain. Also, three of the arthritis participants had minimal pain at the time of testing (pain rating of 1/10). Whether patients have incidental or continuous hand pain can influence the response to quantitative sensory testing,[55] but it is unknown if this has the same impact on cortical excitability. It is notable that there

were no correlations between pain intensity (SFMPQII) and measures of corticomotor excitability

identified in the current study.

Conclusion

We provide novel evidence of cortical disinhibition in people with painful hand arthritis that is

related to the duration of pain. Given the lack of changes in overall corticomotor excitability, we

suggest this arises through specific alterations in intracortical inhibitory and facilitatory pathways

that become more prominent over time. There were no indications of impaired motor learning in

people with hand arthritis and we are unable to support the hypothesis that changes in intracortical

excitability are related to impaired motor performance or learning. Instead, we observed similar

training-induced motor cortex reorganisation and greater improvements in motor skill performance

in people with hand arthritis compared to age- and gender-matched controls. This suggests that

cortical disinhibition does not impair the potential for training-induced neural plasticity or gains in

motor performance.

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Figure legends

Figure 1. Example data from an individual participant showing how the baseline and training twitch directions were determined. **A)** Location of individual twitch responses to TMS (black dots) and the mean twitch direction (open triangle and dotted line). **B)** The baseline twitch zone was a 45° window centring on the mean baseline twitch direction. The voluntary training twitch direction was 180° from the baseline twitch direction.
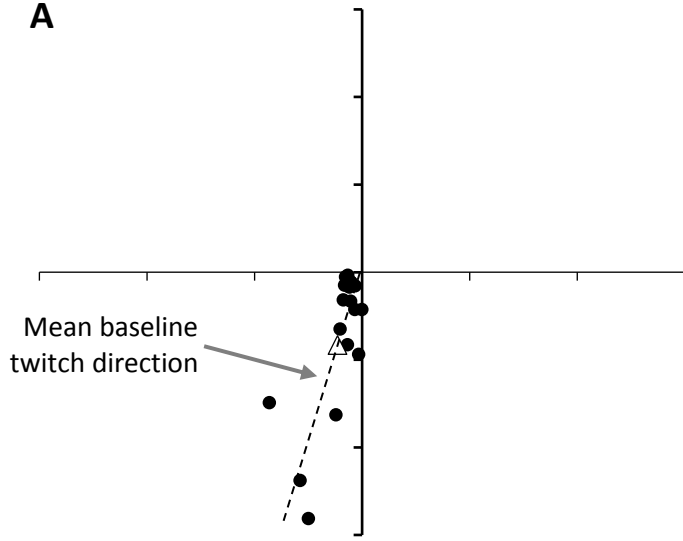
Figure 2. Group data showing the stimulus-response curves for the arthritis and control groups. Error bars are 1 SEM. MEP = motor evoked potential; RTh = rest threshold.

Figure 3. Example stimulation-induced and training twitch data from one control participant. The top charts show stimulation-induced twitch direction at Baseline **(A)**, Post 0 **(B)**, and Post 10 **(C)**. Each dot represents one stimulus; triangles indicate the mean twitch direction. **D.** Voluntary training twitches. Each dot represents one voluntary twitch. **E.** Vector diagram showing the mean stimulation-induced training direction at each assessment period. Note the shift towards the training direction following training.

Figure 4. Group data showing the percent of stimulation-induced twitches that were in the baseline **(A)** and training **(B)** zones at each assessment point. Training was undertaken between baseline and post 0. The graphs show a reduction in the percent of stimulation-induced twitches in the baseline zone following training, and an increase in the number of stimulation-induced twitches in the training zone following training. Error bars are 1 SEM. * = significant difference from baseline ($P<0.05$).
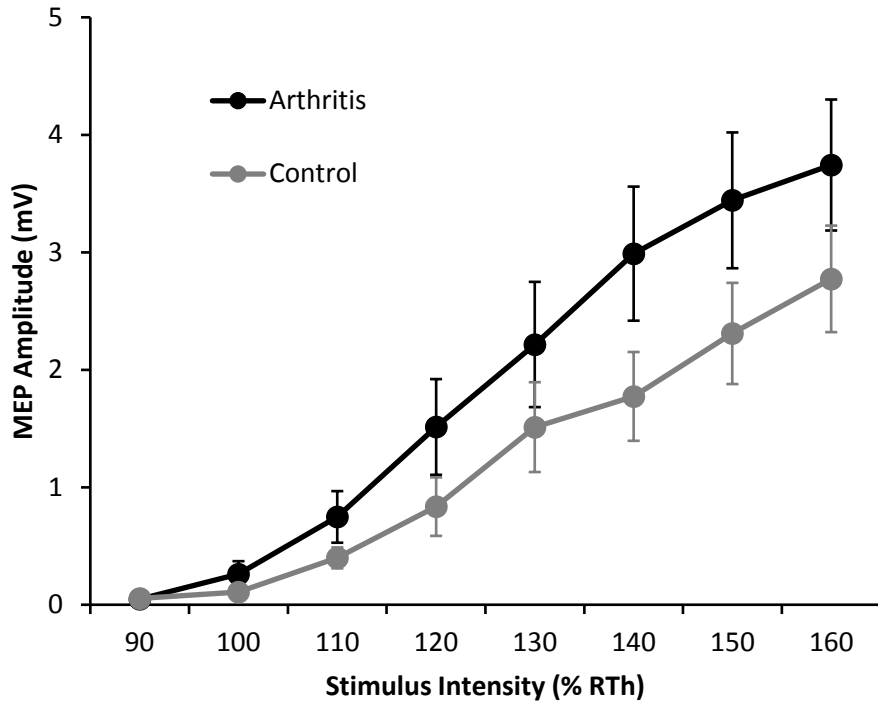
Figure 5. Graphs showing the correlation between **(A)** pain duration and short-interval intracortical inhibition ($SICI_{80}$), and **(B)** pain duration and short-interval intracortical facilitation ($SICF_{1.4}$).
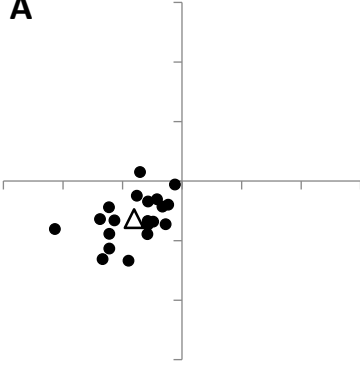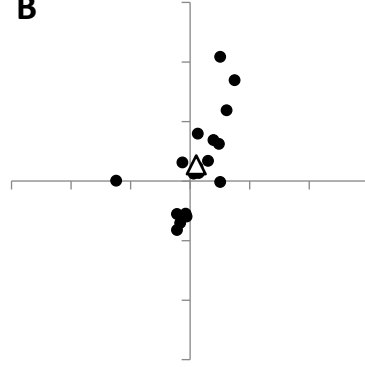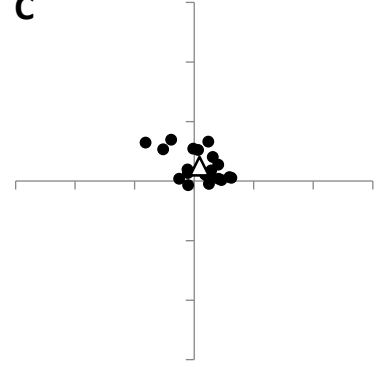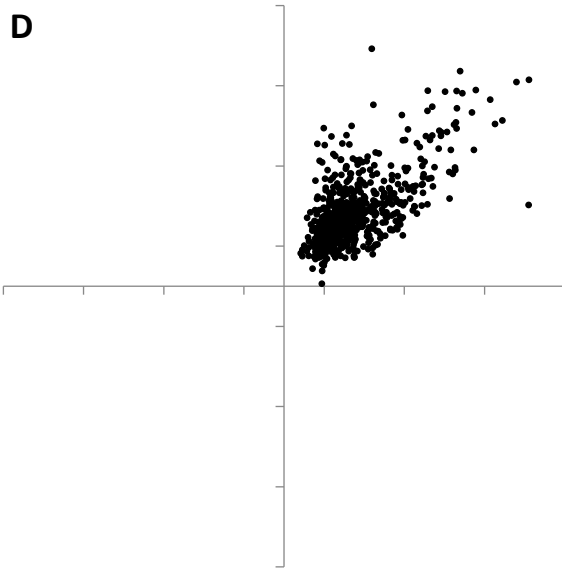
A

Mean baseline
twitch direction

B

Training zone

Baseline zone

A

B

C

D

E

Baseline

Post 0

Post 10

A

B

A

SICI$_{80}$ vs Pain duration (years)

r=0.60; P=0.002

B

SICF$_{1.4}$ vs Pain duration (years)

r=0.48; P=0.02
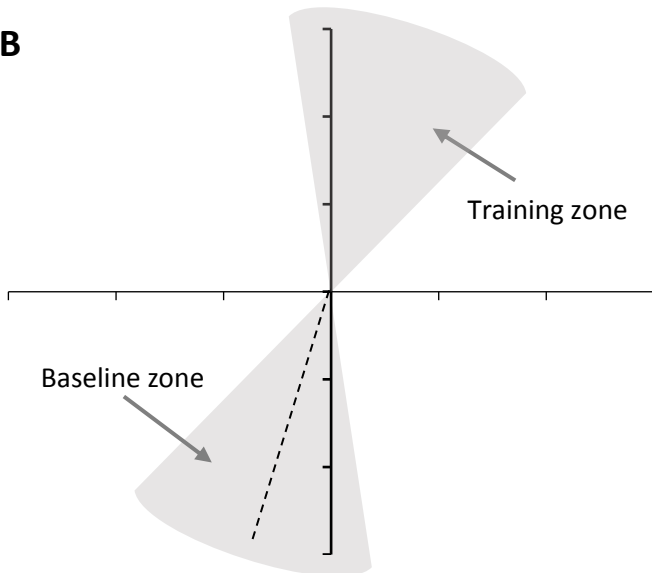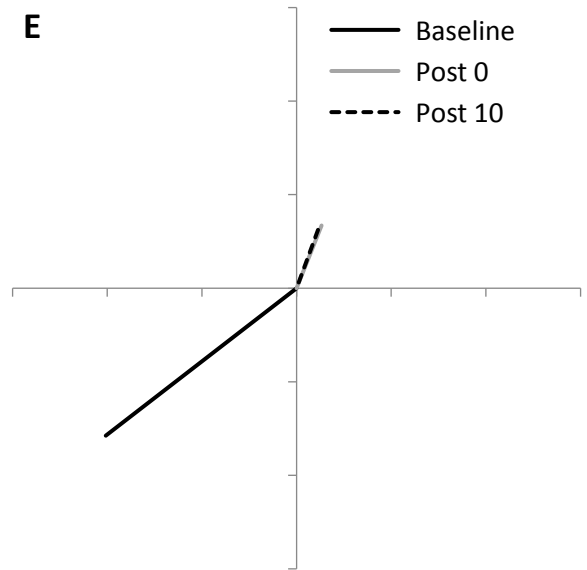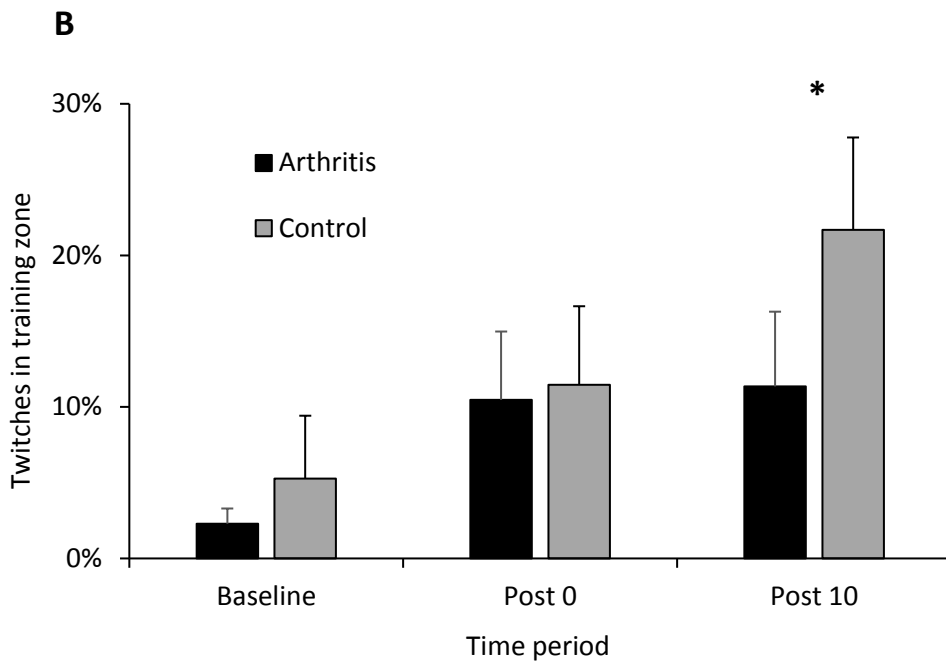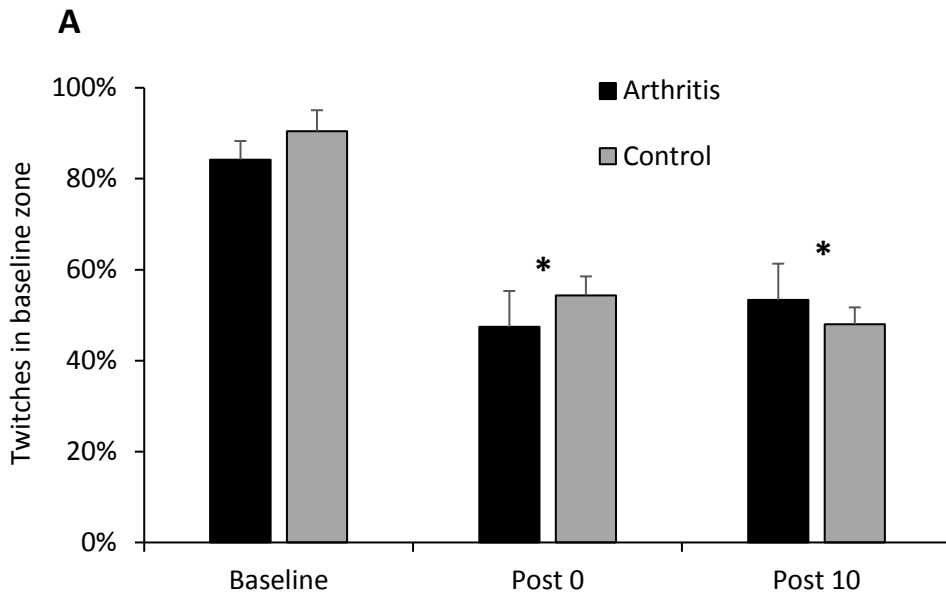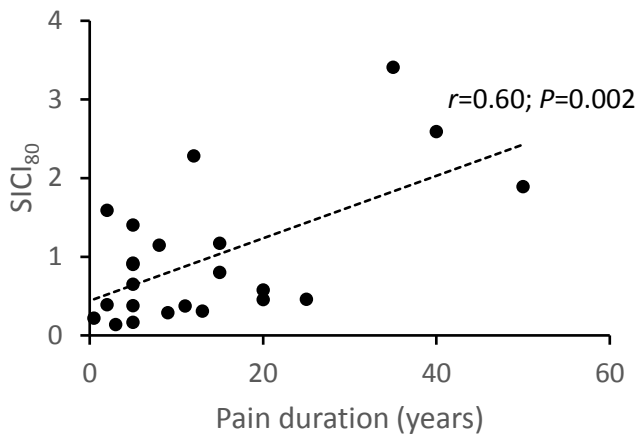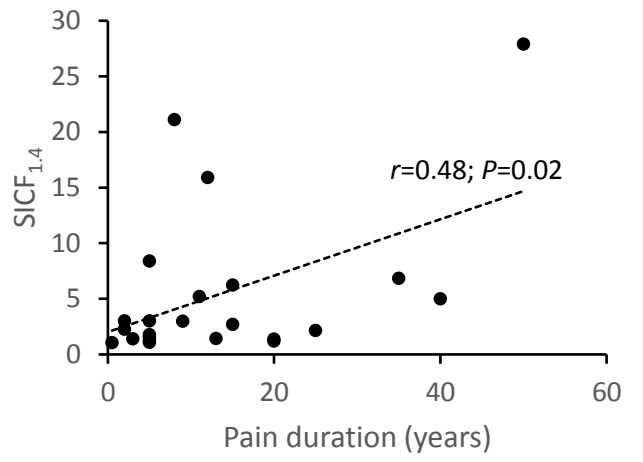
Table 1. Participant characteristics. Data are mean±standard deviation.

	Arthritis group (*N*=23)	Control group (*N*=20)
Age (years)	72±6	71±7
Gender	17 female	14 female
BMI (kg/m^2)	27.5±5.5	25.8±3.4
Hand dominance	21 right	20 right
Pain duration (years)	13.5±13.1	-
SFMPQII (out of 220)	48±31	-
AUSCAN (out of 150)	85±27	-

BMI = body mass index; SFMPQII = Short-Form McGill Pain Questionnaire version II; AUSCAN = Australian/Canadian Hand Osteoarthritis Index.

Table 2. Summary information of corticomotor excitability measures for the two groups. Data are mean±standard deviation.

	Arthritis group (*N*=23)	Control group (*N*=20)	*P*-value
Rest threshold (%MSO)	51±10	51±7	0.97
Boltzmann parameters			
MEP_{max} (mV)	4.3±3.7	3.2±1.9	0.26
m	8.9±4.5	10.5±4.6	0.29
*s*50 (%)	129±18	131±13	0.62
TS_{1mV} amplitude (mV)	0.83±0.88	1.14±0.86	0.18
$SICI_{70}$	0.72±0.57	0.60±0.46	0.37
$SICI_{80}$	0.98±0.86	0.57±0.32	0.03*
$SICF_{1.4}$	5.4±7.0	2.1±1.3	0.03*
$SICF_{2.8}$	2.7±2.3	1.8±1.0	0.08
LICI	0.88±1.5	0.59±0.65	0.43
Silent period (ms)	131±33	135±29	0.69

MSO = maximal stimulator output; SICI = short interval intracortical inhibition; SICF = short interval intracortical facilitation; LICI = long interval intracortical inhibition. * = significant difference between groups.

Table 3. Pearson correlation coefficients between the two measures of corticomotor excitability that were significantly different in the arthritis group and the clinical and training data.

	Pain duration	SFMPQII	AUSCAN	Training accuracy	Learning %
SICI$_{80}$	0.60**	0.31	-0.16	0.21	0.14
SICF$_{1.4}$	0.48*	0.21	-0.05	0.21	0.16

SICI = short interval intracortical inhibition; SICF = short interval intracortical facilitation; SFMPQII = Short-Form McGill Pain Questionnaire version II; AUSCAN = Australian/Canadian Hand Osteoarthritis Index. Training accuracy is the overall measure of the number of accurate twitches during training. Learning % is the difference in accuracy between the 1st and 10th training epochs. * = $P<0.05$; ** = $P<0.01$.