Effects of a Force Production Task and a Working Memory Task on Pain Perception

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Abstract: The goal in the current study was to examine the analgesic effects of a pinch grip-force production task and a working memory task when pain-eliciting thermal stimulation was delivered simultaneously to the left or right hand during task performance. Control conditions for visual distraction and thermal stimulation were included, and force performance measures and working memory performance measures were collected and analyzed. Our experiments revealed 3 novel findings. First, we showed that accurate isometric force contractions elicit an analgesic effect when pain-eliciting thermal stimulation was delivered during task performance. Second, the magnitude of the analgesic effect was not different when the pain-eliciting stimulus was delivered to the left or right hand during the force task or the working memory task. Third, we found no correlation between analgesia scores during the force task and the working memory task. Our findings have clinical implications for rehabilitation settings because they suggest that acute force production by one limb influences pain perception that is simultaneously experienced in another limb. From a theoretical perspective, we interpret our findings on force and memory driven analgesia in the context of a centralized pain inhibitory response.

Perspective: This article shows that force production and working memory have analgesic effects irrespective of which side of the body pain is experienced on. Analgesia scores were not correlated, however, suggesting that some individuals experience more pain relief from a force task as compared to a working memory task and vice versa.

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Key words: Force, muscle contraction, working memory, analgesia, pain, cognition.
paradigms muscle contractions and pain elicitation have not occurred at the same time and for a similar duration. This has prevented firm conclusions from being drawn on the existence of a centralized pain inhibitory response when force production and pain occur simultaneously.

Previous studies have also shown analgesic effects when a working memory task is coupled with pain-eliciting stimulation to the left hand and left forearm. Other studies show similar effects during a Stroop task and a verbal attention task with stimulation delivered to the right forearm and right foot, respectively. Together, these studies suggest that cognition also influences pain perception via a centralized pain inhibitory response that is independent of the spatial location of the pain, but this suggestion has not been directly tested.

We have developed a novel experimental paradigm that allows us to separately measure pinch grip-force production and working memory performance during the delivery of a constant pain-eliciting thermal stimulus to the left or right hand. This paradigm allows us to control for visual distraction during both tasks and to examine whether a centralized pain inhibitory response during each task is related. We tested 3 hypotheses: 1) pain perception will be reduced when force is produced by the right hand and pain is delivered to the left or right hand, 2) pain perception will be reduced when a working memory task is performed while pain is delivered to the left or right hand, and 3) analgesic scores associated with force production and working memory will be positively related, suggesting that a common centralized pain inhibitory response may be associated with both tasks.

Methods

Subjects

Thirty-eight healthy right-handed adults with normal or corrected-to-normal vision and not taking any pain medications participated (19 female, 19 male; mean = 20.78 y, range: 18–43 y). Each subject provided informed consent to all procedures, which were approved by the local institutional review board and were in accord with the Declaration of Helsinki. Exclusion criteria were any history of neurologic disease, including any history of chronic pain or any current episode of acute pain. Subjects who verbally self-reported any history of these disorders were excluded during prescreening. All subjects completed the state and trait segments of the State-Trait Anxiety Inventory (STAI-S, STAI-T), the Beck Depression Inventory, the Pain Anxiety Symptoms Scale, Pain Catastrophizing Scale, and the Tampa Scale of Kinesiophobia. All scores were within the normal range of responses typically given by healthy adult subjects (STAI-S: mean = 28.5, SD = 9.20; STAI-T: mean = 33.30, SD = 8.87; Beck Depression Inventory: mean = 2.0, SD = 2.67; Pain Anxiety Symptoms Scale: mean = 54.83, SD = 17.4; Pain Catastrophizing Scale: mean = 11.5, SD = 8.55, Tampa Scale of Kinesiophobia: mean = 29.78, SD = 4.25).

Pinch Grip-Force Task

Pinch grip-force was always produced by the index finger and thumb of the right hand. During the practice session, each subject’s maximum voluntary contraction (MVC) was estimated using a force transducer (Jamar Hydraulic Pinch Gauge; Lafayette Instrument Co, Lafayette, IN). Subjects were asked to sustain a contraction of maximum force for three 5-second trials. Trials were separated by 60-second periods of rest. The MVC was calculated as the average of the 3 peak force levels. Mean MVC across subjects was 64.75 N (SD = 16.4 N). The force transducers used were ELFF-B4 model load cells constructed from piezoresistive strain gauges measuring force up to 100 N (Measurement Specialties, Hampton, VA). Force data were collected by Coulbourn Instruments Type B V72-25 amplifiers (Coulbourn Instruments, Allentown, PA) at an excitation voltage of 5 V. The force signal was transmitted via a 16-bit analog-digital converter and digitized at 125 Hz. The summed output from the 2 force transducers (index finger and thumb) was presented to the subject using a visual display on the computer screen. The force output was displayed on a 40-inch liquid crystal display screen at a resolution of 1,600 × 1,024 pixels and a refresh rate of 59 Hz. The subject sat 50 inches from the screen. Force production was guided by real-time visual information consistent with the paradigm shown in Fig 1A, and with previous force control studies. During the rest period and during the task, 2 bars were visible to the subject. A white bar represented the target force level that was set at 25% of each subject’s MVC. A red/green force bar was controlled by the subject and provided real-time visual information of force production. When the force bar turned green, the subject’s goal was to match the green bar with the white bar. The subject produced force until the green bar turned red. Each task was 15 seconds long and included 5 force pulses. Each pulse was 1.8 seconds long (bar turns green) and pulses were separated by a 1.2-second rest period (bar turns red). Each trial was followed by a 7.5-second rating period in which subjects rated the level of pain they experienced during the previous 15-second trial. Subjects were instructed to make a rating after every trial. This was especially important for the trials where no stimulation was delivered because we wanted to determine whether any pain was experienced as a function of the grip-force task alone. Ratings were always made with the left hand using a keyboard to control a cursor on a visual analog scale (VAS) presented on the screen. As shown in Fig 1A, during experimental trials, 2 verbal descriptors were visible to the subject: “no sensation” on the left side of the scale and “intolerable pain” on the right side of the scale. The range of the rating bar was 0 to 10, with a resolution of .1. As shown in Fig 1A, subjects did not see numbers on the scale. Subjects were familiarized with the rating scale during a practice session. Fig 1B shows an example time series
Figure 1. Experimental paradigm for the force task and the working memory task. (A) The red bar indicates rest. When the bar turned green, subjects produced force during the active condition or watched the green bar move based on a prerecorded force trace from the same subject during the passive condition. Subjects were informed before each block whether the upcoming block was active or passive. During the active force task, 5 pulses of force (1.8 seconds each) were produced separated by 1.2-second periods of rest. Note that only 2 pulses are shown in (A). After each 15-second trial, subjects rated the level of sensation they felt during the preceding trial. (B) An example of the force pulses produced by 1 subject during 1 trial at each temperature condition (baseline, warm, hot). The black lines (left y-axis) represent the force produced by the subject and the red lines (right y-axis) reflect the temperature of the thermode during each representative active trial. (C) Working memory task. Rest was represented by a fixation cross. During each 15-second trial, a sequence of 10 letters was presented on the screen, one at a time. Note that only 2 letters are shown in (C). During the active task, subjects were required to count the number of times a letter was the same as the one presented 2 letters previously. They kept count of the number of hits during each trial and then responded at the end of each trial using their left hand on a keyboard to control a slider on an integer scale. (D) During the presentation of the letters, subjects also received baseline, warm, or hot stimulation (red lines, right y-axis). After the n-back rating, subjects reported the level of sensation they experienced during the previous 15-second trial using the same scale as in the force task. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

of 1 trial of a subject’s force production (black lines: left y-axis) overlapped with the temperature of the thermode (red lines: right y-axis) for the 3 different temperature conditions.

Working Memory Task

The visual display during the working memory task is shown in Fig 1C. Subjects completed a standard 2-back working memory task, which is also termed an n-back task. During each trial, a series of 10 white letters were presented one at a time on a black background on the visual display. Each letter was visible for 1 second and letters were separated by .5 seconds. Subjects were required to count the number of hits, which was the number of times the presented letter was the same as the letter presented 2 letters previously. Following each trial, subjects reported the number of hits during the 15-second trial using their left hand to control a keyboard to move a cursor on an integer scale shown on the screen. The scale range was 0 to 5. Subjects had 6 seconds to register their response. The correct number of hits in each trial was pseudo-randomized across conditions, and a unique series of letters was presented during each trial. Next, during a 7.5-second rating period, subjects used their left hand to make an intensity rating on the same VAS as in the force condition. Aside from the additional n-back response time.
and the mean hot temperature was 46.01 (R² < .65). Hence, 36 participants (18 female, 18 male) were excluded from the analysis because all subjects. The baseline temperature was set at 32 °C. In all subjects, the ratings were similar and whether the hot temperature was rated similarly across subjects. The baseline temperature was set at 32 °C. When switching stimulation to the other hand, a rating of 2 to 3 was selected as the warm temperature corresponding to a rating of 6 to 8 was selected as balanced across subjects). After calibration, the temperature between 41 and 48 °C was delivered twice in a random order. After each trial, subjects rated perceived pain intensity during the trial by moving a cursor on a digital VAS. For each subject, ratings were plotted against their corresponding temperatures. To qualify for the study, an individual's ratings of the pain threshold of each subject was determined through a calibration protocol. Subjects first went through a practice session where they were made familiar with the rating scale. The scale ranged from 0 = “no sensation” to 10 = “intolerable pain.” The calibration paradigm consisted of 16 trials; the duration of each trial was 15 seconds. Each temperature between 41 and 48 °C was delivered twice in a random order. After each trial, subjects rated perceived pain intensity during the trial by moving a cursor on a digital VAS. For each subject, ratings were plotted against their corresponding temperatures. To qualify for the study, an individual's ratings of the applied temperatures had to be consistent between ratings of 2 and 10 (R² > .65). Data from 2 subjects (1 male, 1 female) were excluded from the analysis because of inconsistent ratings during the calibration period (R² < .65). Hence, 36 participants (18 female, 18 male) were included in the analyses. The mean R² value was .85 (SD = .06). Full calibrations were completed on the first hand that received stimulation (which was counterbalanced across subjects). After calibration, the temperature corresponding to a rating of 6 to 8 was selected as the hot temperature and the temperature corresponding to a rating of 2 to 3 was selected as the warm temperature. When switching stimulation to the other hand, a short calibration procedure was used to determine whether the hot temperature was rated similarly across both hands. In all subjects, the ratings were similar and so the same temperature was used for both hands for all subjects. The baseline temperature was set at 32 °C. The mean warm temperature was 42.51 °C (SD = .91) and the mean hot temperature was 46.01 °C (SD = 1.97).

For all tasks, the left and right hand were in a pronated position. Thermal stimuli were delivered to the thenar eminence of the hand. The thermode was strapped to the hand using hook-and-loop, and cushioning was placed under the forearm to prevent downward pressure from the hand to the thermode. The thermode remained in place during the entire block of trials and was not removed prior to each rating being made. The grip-force apparatus (right hand) and the keyboard (left hand) were raised and positioned so that when the thermode was attached to the hand, finger and thumb movements occurred with minimal change in position or pressure of the thermode on the hand. The LabVIEW program (National Instruments, Austin, TX) that collected and displayed the force task and the working memory task also controlled the timing of the thermal stimulation via a transistor-transistor logic pulse to the PATHWAY system. During each 15-second trial, the temperature of the thermode was set at the baseline temperature or at each subject’s warm or hot temperature. During warm and pain-eliciting stimulation trials, the thermode surface was heated to the target temperature at a rate of 70 °C/s, and this temperature was maintained for the duration of the 15-second trial. The temperature returned to the baseline at a rate of 40 °C/s at the end of the 15-second trial. The fast rate of heating and cooling of the thermode ensured that the thermal stimulation was synchronized with the force task. During the rest period between trials, the thermode was set at the baseline temperature. Note that although the thermal stimulation was constant for 15 seconds, the force task cycled between force pulses and brief rest periods, and the working memory task presented letters that were also separated by brief rest periods. Hence, thermal stimulation was matched in terms of total trial duration (ie, 15 seconds), but brief rest periods did occur within the force production task and the working memory task during which thermal stimulation remained constant.

**Experimental Paradigm**

The experimental paradigm for the force production task and the working memory task were designed to be as consistent as possible in terms of task timing, hand position, stimulation duration, and control conditions. In addition to allowing us to examine analgesia during each task separately (hypotheses 1 and 2), our approach also allowed us to examine the relation in analgesia scores between tasks (hypothesis 3). For the force task and the working memory task, there were active and passive conditions. During active conditions, subjects produced force with their right hand or performed the working memory task. During passive conditions, subjects did not produce force or complete the working memory task but viewed a prerecorded force trace or a series of letters that did not have to be remembered. Visual information was therefore consistent across active and passive conditions for each task. For the force task, the prerecorded force trace was recorded during each participant’s practice session. During the practice session subjects produced force during each temperature condition to familiarize themselves with the experimental paradigm. Force traces were recorded during accurate practice trials and were played back to the subject later during experimental trials for the corresponding passive conditions. This meant that the passive condition could occur first in the experimental paradigm and order effects were avoided. Because of the relative ease of the task, subjects were able to perform the task accurately during the practice session after 1 or 2 trials. Thermal stimulation was delivered during both active and passive conditions, and ratings were always made using the left hand in both conditions. This allowed us to calculate analgesia scores while controlling for visual stimuli between conditions. Subjects completed a total of 8 blocks of
experimental trials: 4 blocks for the force task and 4 blocks for the working memory task. For each task, thermal stimulation was delivered to the left hand (2 blocks: 1 active, 1 passive) and to the right hand (2 blocks: 1 active, 1 passive). Within each block, the task type, the site of stimulation, and the visual information was constant. The only independent variable that changed during a block was the temperature of the thermal stimulation, which was at a baseline temperature (2 trials), a warm temperature (3 trials), or a hot temperature (3 trials). Temperatures within each block were pseudo-randomized such that the same temperature was never presented twice in a row. A 90-second rest interval separated trials 4 and 5 to provide a standardized rest period within each block and to help avoid habituation, sensitization, and fatigue affects. We also controlled for sensitization and habituation effects by pseudo-randomizing block order with the following constraints: half the subjects completed the first 4 blocks with stimulation on their right hand and half completed the first 4 blocks with stimulation on their left hand. Half the subjects completed 2 blocks (active/passive) of the force task first and half completed 2 blocks (active/passive) of the working memory task first. Finally, half the subjects completed the passive block first, and half the subjects completed the active block first. Nonsignificant paired t-tests between the first and last rating, irrespective of task, for the passive hot condition on each hand suggested that habituation across trials was not an issue (left hand: \( t[35] = 1.95, P > .05 \); right hand: \( t[35] = -.954, P > .05 \).

**Data Analysis**

**Force Task**

Force data was analyzed using custom algorithms in LabVIEW. The force–time series data were digitally filtered using a fourth-order Butterworth filter with a 20-Hz low-pass cut-off. Force production was characterized by measures of mean force amplitude and force variability (SD). Force amplitude and force variability were extracted from the middle 1 second of each pulse. The middle 1 second of the pulse was calculated following identification of the onset and offset of each pulse. The onset of each contraction was identified as the time point where the force rose above 2 times the baseline value. The offset of each contraction was identified as the next time point where force fell below 2 times the baseline value. Baseline values were calculated as the mean force amplitude during the 300 ms prior to each 15-second block. The summary statistic for each force-dependent variable was the mean score calculated from all the pulses in each condition. Separate 2-way (temperature [baseline, warm, hot] \( \times \) site [left stimulation, right stimulation]) repeated measures analyses of variance (ANOVAs) were run for each dependent variable.

**Working Memory Task**

Consistent with prior work, task performance was calculated as the ratio between blocks with a correctly indicated number of n-back targets and the total number of blocks per condition. The summary statistic was the mean ratio score for each condition. Mean scores for each condition were compared with a 2-way repeated measures ANOVA (temperature [baseline, warm, hot] \( \times \) site [left stimulation, right stimulation]).

**Rating Task**

Intensity ratings were made after every trial. A mean rating score was calculated from all trials in each condition. Our first 2 hypotheses predicted that force production and working memory would influence the perception of a pain-eliciting stimulus delivered to the left and right hand. We therefore ran a 3-way ANOVA (task: [force production, working memory] \( \times \) site [left, right] \( \times \) engagement [active, passive]) to examine differences in absolute ratings across all conditions when hot thermal stimulation was delivered. Control analyses used the same ANOVA model to examine ratings between conditions during baseline and warm temperature trials. Our third hypothesis predicted that analgesic scores during the force production task and the working memory task would be related. To test this hypothesis, we first subtracted ratings during each active condition from ratings during its corresponding passive condition at the hot temperature. We then performed a correlation analysis between scores for the force production task and the working memory task using Pearson correlation coefficient.

For all analyses, significant effects were followed up with paired t-tests corrected for multiple comparisons using the Bonferroni correction. For analyses in which the sphericity assumption was violated, Greenhouse-Geisser degrees of freedom corrections were applied and are reported. Significance level was set at \( P < .05 \).

**Results**

**Pinch Grip-Force Task**

Mean force amplitude and mean variability for all conditions is shown in Table 1. The amplitude of force production did not differ as a function of temperature (\( F[1.4, 49.01] = .39, P = .608 \)), site (\( F[1, 35] = 2.79, P = .104 \)), or an interaction between temperature and site (\( F[1.45, 50.79] = 1.95, P = .163 \)). Mean force across all conditions was 24.54% of MVC. Mean variability (.91% of MVC) also did not vary as a function of temperature (\( F[1, 35] = 1.99, P = .143 \)), site (\( F[1, 35] = 1.99, P = .167 \)) or an interaction between them (\( F[2, 70] = 1.40, P = .253 \)).

**Working Memory Task**

One subject was not included in the analysis because of incomplete scoring data. Ratio scores from each site and temperature condition were compared in the 2-way repeated measures ANOVA. There was no main effect of temperature (\( F[2, 68] = 1.91, P = .156 \)) or site (\( F[1, 34] = .77, P = .387 \)), and the interaction of temperature and site was not significant (\( F[2, 68] = .16, P = .853 \)).
The overall mean ratio across all conditions was .59 (SE = .039).

**Rating Data**

The primary aim was to examine the effect of task, site, and engagement on stimulation intensity ratings when a hot pain-eliciting stimulus was delivered to the subject during task performance. The corresponding 3-way repeated measures ANOVA revealed a significant main effect of engagement (F[1, 35] = 48.97, \(P < .001\)) but not task (F[1, 35] = 3.72, \(P > .05\)) or site (F[1, 35] = .63, \(P > .05\)). The main effect of engagement was superseded by a significant task \(\times\) engagement interaction (F[1, 35] = 7.93, \(P < .01\)). Data were collapsed across site, and paired t-tests comparing active and passive conditions revealed significant effects of engagement for the force task (t[35] = 5.43, \(P < .001\)) and the working memory task (t[35] = 5.67, \(P < .001\)). Fig 2 shows rating data for the force production task (left) and the working memory task (right) for passive (P) and active (A) trials at each temperature. Data are collapsed across left and right site. The temperature conditions are represented by circles (hot), triangles (warm), and squares (baseline). For the force task, 31/36 (86%) subjects had a positive analgesic score (passive rating > active rating), with ratings decreasing by 11% from the passive to the active task. For the working memory task, 32/36 subjects (89%) had positive analgesic scores and ratings decreased by 17% from the passive to the active task. The temperature conditions are represented by circles (hot), triangles (warm), and squares (baseline). As expected, ratings increased as a function of temperature, and analgesic effects were not found at warm or baseline temperatures for either task. At the hot temperature, ratings during both tasks were significantly higher for the passive trials as compared to active trials. Error bars represent 1 SD. The asterisk represents a significant t-test finding (*\(P < .05\)).

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**Table 1.** Performance and Rating Data for Active and Passive Conditions for the Force Production Task and the Working Memory Task for Each Site (Left, Right) and Each Temperature (Baseline, Warm, Hot)

<table>
<thead>
<tr>
<th>Site</th>
<th><strong>Active</strong></th>
<th><strong>Passive</strong></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Baseline</td>
<td>Warm</td>
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<tr>
<td></td>
<td>M</td>
<td>SD</td>
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<tr>
<td></td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td><strong>Force task</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amplitude (%MVC)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>24.56</td>
<td>.65</td>
</tr>
<tr>
<td>Right</td>
<td>24.49</td>
<td>.61</td>
</tr>
<tr>
<td>Variability (%MVC)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>.87</td>
<td>.05</td>
</tr>
<tr>
<td>Right</td>
<td>.86</td>
<td>.05</td>
</tr>
<tr>
<td>Rating</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>.44</td>
<td>.82</td>
</tr>
<tr>
<td>Right</td>
<td>.21</td>
<td>.40</td>
</tr>
<tr>
<td><strong>Memory task</strong></td>
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<td></td>
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<tr>
<td>Performance (ratio)</td>
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<tr>
<td>Left</td>
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<td>.35</td>
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<tr>
<td>Right</td>
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<td>.40</td>
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<tr>
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<tr>
<td>Right</td>
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<td>.56</td>
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</tbody>
</table>

Abbreviations: M, mean; SD, standard deviation.

NOTE. Performance data were not collected during passive conditions. Variability during the force task represents the standard deviation of the force output.
within-trial changes in force production. We also used a passive contraction, which led to an analgesic effect emerging earlier in the current study. Other methodological differences may also account for the correlation between analgesia scores during the force production task and the working memory task.

Discussion

The goal in the current study was to examine the analgesic effects of force production and a working memory task when pain-eliciting thermal stimulation was delivered to the left or right hand during task performance. Our experiments revealed 3 novel findings. First, we showed that acute isometric force contractions elicit an analgesic effect when pain-eliciting thermal stimulation was delivered during task performance. Second, the magnitude of the analgesic effect was not different when the pain-eliciting stimulus was delivered to the left or right hand during the force task and the working memory task. Third, we found no correlation between analgesia scores during the force production task and the working memory task.

During rehabilitation, patients are often required to make movements that are short in duration, have to be repeated frequently, and elicit pain for the duration of the movement. The current study was partially motivated by these observations because although previous studies have demonstrated analgesic effects of force contractions, they have done so using serial paradigms in which the contraction and the pain do not occur simultaneously.19,25,27 We extend these findings by demonstrating an analgesic effect when acute force production and pain-eliciting stimuli are delivered simultaneously, for similar amounts of time, and involve the same or different hand. Our findings contrast a previous study that did not find analgesic effects when a 5-second pain-eliciting stimulus was delivered 30 or 60 seconds after the onset of a contraction but did find effects when the same stimulus occurred 90 seconds after onset of the contraction.54 One possibility is that analgesia can occur during the first 15 seconds of a contraction and then dissipate before reemerging 90 seconds after onset. An alternative explanation is that a pulsing pinch grip-force task increases motor system activity to a greater extent than a sustained contraction,43 which led to an analgesic effect emerging earlier in the current study. Other methodological differences may also account for the contrasting findings. In the current study, the duration of the thermal stimulus was 15 seconds as compared to 5 seconds. Subjects in the current study also reported stimulus intensity after the trial using a digital VAS as compared to a verbal report after each stimulus but not during the contraction. We also used a passive control condition to account for visual distraction as an explanation for differences between the active and passive conditions. Given that force production is one task and evaluating the stimulation could be considered a second task, we controlled for a dual-task interpretation by including a force-warm condition. If lower ratings in the active force–hot condition were due to dual-task effects, one would expect the active force–warm condition to also be rated lower than its corresponding passive control condition. This was not the case. Accounting for visual distraction and dual-task conditions is consistent with a recent review article that supported the use of appropriate control conditions when examining exercise-induced analgesia.42

A third explanation relates to a centralized pain inhibitory response that suggests that engaging motor circuits influences activity in pain circuits at the level of the spinal cord and/or brain. This suggestion is based on our finding that analgesia was not different when force production and pain-eliciting stimuli were delivered to the same as compared to different hands, which is consistent with previous studies that used serial27,47 and parallel experimental paradigms.29,54 The gate control theory suggests that the sensory input generated by force production may have activated inhibitory interneurons that inhibited pain signals prior to them reaching the spinal cord. However, this theory cannot explain the analgesic effect that emerged when force production and pain-eliciting stimuli occurred simultaneously on different hands. Direct inhibition at the spinal level via the crossing of sensory and motor neurons is also a possibility, but the available evidence suggests that a centralized inhibitory circuit is the more likely explanation. This interpretation is consistent with repetitive transcranial magnetic stimulation studies (rTMS) that have shown that rTMS over one side of primary motor cortex (M1) leads to an analgesic effect on both sides of the body even though no force is produced.18,32,33,35,46 This suggests that M1 may be an entry port for the modulation of pain irrespective of its
spatial location. Previous neuroimaging studies have demonstrated M1 activity during a pinch grip-force task similar to the one used in the current study.8-10,14,23,43,60 Hence, our analgesic effects may have been driven by increased activity in motor circuits that influenced activity in downstream pain processing networks that include midcingulate cortex, insula, and periaqueductal gray.1,6,12,13,30,36,39,48,51 Although stimulation of M1 has been shown to attenuate chronic pain in conditions such as fibromyalgia, analgesic effects associated with voluntary isometric contractions in patient populations have been mixed.20,22,31,54 These observations, coupled with differences between exogenous and endogenous pain, voluntary and involuntary engagement of the motor system, and potential age- and sex-related differences, suggest that translating the current findings to clinical populations may not be straightforward. Future studies that replicate our protocol but also assess other potential mechanisms such as skin temperature, increased secretion of beta-endorphins, and blood pressure22,24,26 may help translate the current findings to clinical populations.

Although previous studies have examined the effect of working memory on pain perception,3-5,53 they have not manipulated the side of stimulation in the same individual. Here, we extend these findings by demonstrating that a working memory task has an analgesic effect irrespective of which side of the body the pain is experienced on. Our findings have implications for advancing the shared resources model of pain and cognitive performance because they demonstrate that cognitive performance and/or pain processing share resources,4 consistent with neuroimaging evidence that working memory and pain processes are characterized by overlapping bilateral brain activity.17,45 However, we found no evidence of a pain-related decrement in working memory performance as subjects were able to perform the task with similar accuracy across all stimulation intensities.7,49 Performance ratios were consistent with a recent study that used a similar paradigm and scoring method.53 However, we are cognizant of work that has demonstrated pain-related decrements in cognitive performance.3-5,40,53 Task difficulty may account for why decrements in performance were not found in the current study. Pairing pain-eliciting stimulation with low and high working memory load tasks has shown improved performance on low- as compared to high-load tasks and attenuated pain ratings for high- as compared to low-load tasks.3,53 Effects of pain on task performance are mixed, however, and may be driven by task difficulty such that harder tasks are more susceptible to pain-related decrements as compared to easier tasks.4,5 Together these findings suggest that the task used in the current study was challenging enough to drive an analgesic effect but not so challenging that pain-related decrements in working memory performance emerged.

The current study has a number of limitations. First, it was designed to assess the effects of acute motor and cognitive tasks on exogenous pain perception. Hence, we did not examine the duration of the analgesic effect, which is an important question that needs to be addressed. Second, our findings were limited to self-reported pain ratings, and physiological indices such as blood pressure and secretion of beta-endorphins were not collected. Third, our experiment did not assess other factors that may alter pain ratings such as skin temperature or factors that indicate whether the analgesic effects were associated with changes in the spinal cord and brain. Fourth, the generalizability of our findings to endogenous pain conditions is limited because we assessed changes in pain perception to an acute exogenous thermal stimulus in healthy adults. Future studies are necessary to address these issues.

Our findings suggest that both the force production task and the working memory task engaged a centralized inhibitory response, but no relation was found between the analgesia scores for each task. This finding may be explained by differences in trying to manipulate a visual target during the force task, which engages the visuomotor system,8-10 and trying to remember and count visually displayed letters, which engages the working memory system.3,58 Hence, although each system influences exogenous pain perception at the group level, at the individual level engaging one system instead of the other may have a greater influence on pain perception. Our findings therefore have implications for pain management approaches because they demonstrate that certain individuals may engage a centralized pain inhibitory response more so during a force production task as compared to a working memory task and vice versa.

References


Dose response of isometric contractions on pain perception


54. Staud R, Robinson ME, Price DD: Isometric exercise has opposite effects on central pain mechanisms in fibromyalgia patients compared to normal controls. Pain 118:176-184, 2005


