American Pain Society
RESEARCH
EDUCATION
TREATMENT
ADVOCACY
PUBLISHED BY ELSEVIER

The Journal of Pain, Vol 14, No 10 (October), 2013: pp 1088-1096
Available online at www.jpain.org and www.sciencedirect.com

The Influence of Working Memory Capacity on Experimental Heat Pain

Aya Nakae,* Kaori Endo,† Tomonori Adachi,† Takashi Ikeda,† Satoshi Hagihira,* Takashi Mashimo,* and Mariko Osaka†

**Department of Anesthesiology & Intensive Care, Osaka University Graduate School of Medicine, Osaka, Japan.*
†Osaka University Graduate School of Human Sciences, Osaka, Japan.

Abstract: Pain processing and attention have a bidirectional interaction that depends upon one's relative ability to use limited-capacity resources. However, correlations between the size of limited-capacity resources and pain have not been evaluated. Working memory capacity, which is a cognitive resource, can be measured using the reading span task (RST). In this study, we hypothesized that an individual's potential working memory capacity and subjective pain intensity are related. To test this hypothesis, we evaluated 31 healthy participants' potential working memory capacity using the RST, and then applied continuous experimental heat stimulation using the listening span test (LST), which is a modified version of the RST. Subjective pain intensities were significantly lower during the challenging parts of the RST. The pain intensity under conditions where memorizing tasks were performed was compared with that under the control condition, and it showed a correlation with potential working memory capacity. These results indicate that working memory capacity reflects the ability to process information, including precise evaluations of changes in pain perception.

***Perspective:** In this work, we present data suggesting that changes in subjective pain intensity are related, depending upon individual potential working memory capacities. Individual working memory capacity may be a phenotype that reflects sensitivity to changes in pain perception.*

***Key words:** Working memory capacity, heat pain, individual difference, reading span test, listening span test.*

Substantial evidence exists that pain is closely related to cognitive function.[1,2,18,19] The perception of pain requires attention to noxious stimuli. Changing the focus of attention away from noxious stimuli has been shown to effectively reduce pain.[50] Pain is perceived as less intense when a person is distracted from the pain by a challenging cognitive task,[4,6,22,35,47] such as a working memory task.[27] However, pain increases when it is the focus of attention.[36]

Working memory designates a system involved in the temporary storage and processing of information. Working memory tasks have been used not only as an evaluation tool of memory functions but also as an attention control task.[27]

There are many kinds of working memory tasks, and each task requires various types of brain functions, including executive function. Executive function is an umbrella term for many cognitive processes, including maintenance of long-term goals, planning, the ability to ignore distracting information, and the ability to suppress inappropriate responses. As such, executive control is an important part of the working memory system and is responsible for maintaining relevant items in short-term memory storage, removing relevant items from short-term memory storage, removing items no longer needed, and ignoring items that are not relevant to the task at hand. Brain imaging studies have demonstrated that activity evoked by pain and

Received January 19, 2013; Revised April 6, 2013; Accepted April 12, 2013.
This work was supported by Grants-in-Aid (JSPS #23240036: M.O. and JSPS #23592287: S.H.) from the Ministry of Education, Culture, Sports, Science and Technology, Japan. This work was partially supported by the global COE program "Center of Human-friendly Robotics Based on Cognitive Neuroscience."
No conflicts of interest exist for any of authors, nor is there commercial interest to be disclosed in the execution or the experiment or in the preparation of the manuscript.
Address reprint requests to Aya Nakae, Department of Anesthesiology & Intensive Care, Osaka University Graduate School of Medicine, 2-2 Yamadaoka, Suita, Osaka 565-0871, Japan. E-mail: anakae@anes.med.osaka-u.ac.jp
1526-5900/$36.00

http://dx.doi.org/10.1016/j.jpain.2013.04.005

attention-demanding tasks are typically located in similar regions,[44] leading to the hypothesis that these regions play a role in general salience detection.[14,17] Moreover, previous studies have shown that patients with chronic pain have poor executive functioning.[1]

The reading span task (RST) is a common memory span task in which participants are required to read a few sentences and remember a target word in each sentence.[13] It can used to analyze individual differences in working memory capacity, which is a cognitive resource. The RST is a complex verbal test because it draws upon storage and processing, which are elements of working memory. In contrast, simple verbal tests such as a word span test require only storage.[28] The listening span test (LST) is a variant of the RST in which participants are required to listen to a few sentences and remember the last words in each sentence. In an imaging study, we previously showed that individuals with a higher working memory capacity had higher connectivity between the anterior cingulate cortex (ACC) and prefrontal cortex (PFC) while performing an RST used to evaluate executive functioning.[33] However, no studies on experimental pain using the RST or on the correlation between pain and working memory capacity as evaluated by the RST have been conducted.

In the present study, we hypothesized that an individual's potential working memory capacity and subjective pain intensity are related.

Methods

Participants

The participants were 31 healthy volunteers with normal or corrected-to-normal vision; no history of neurologic, psychiatric, or chronic pain disorders; and no current psychotropic or analgesic drug use. All 31 patients (mean age, 23.67 $\pm$ 2.31 years; 9 women) were recruited for the experiment. Participants provided written informed consent. The experimental procedures were approved by the local ethics committee.

Stimuli

We employed graded heat as the noxious stimulus and applied the maximum temperature that each participant could endure. Thermal stimuli were delivered in a highly accurate fashion to the ventral surface of the nondominant forearm via a 30 $\times$ 30 mm^2 Peltier device (Pathway; Medoc Ltd, Ramat Yishai, Israel). This device was attached to the forearm with a strap, moved to an adjacent area after the presentation of every third stimulus to avoid habituation or sensitization to repeated stimulation, and maintained at a baseline temperature of 32°C. Stimulus temperatures were delivered with rise and fall rates of 8°C/second and were feedback controlled.

To avoid a floor effect, we set the stimulation temperature during the working memory task to the maximum temperature that the participants could endure and that was within the safety settings of the stimulator. The participants underwent a trial stimulation (15-second plateau stimulation and 60-second rest [32°C] at 5 temperatures: 40°C, 42°C, 44°C, 46°C, and 48°C) in ascending order and evaluated the pain intensity using a continuous visual analog scale (VAS) evaluation system (CoVAS; Medoc Ltd). Then, to evaluate the pain intensity when the subjects were not engaged in the task and to determine the actual stimulation temperature, 3 different stimuli were applied randomly and repeatedly (30-second plateau stimulation and 60-second rest [32°C], 4 repetitions) across temperatures varying by 1°C. These temperatures were determined in the initial test using the maximum temperature at which the participants reported a pain intensity of less than 80/100.[39] For example, if the participants described their maximum pain intensity as 90/100 at 48°C, the next stimulation temperatures were 45°C, 46°C, and 47°C. The stimulation temperature was established as the maximum temperature at which the participants evaluated their pain intensity as less than 80/100. For safety, the stimulation temperature was maximally limited to 48°C when we applied the 60-second tonic stimulation. Thus, if the participants felt pain under 80 mm at 48°C, the stimulation temperature was set at 48°C.

Working Memory Task

RST

To evaluate working memory capacity, all participants performed the RST. This test is an established method of assessing baseline working memory capacities that has been confirmed to predict reading efficiencies in a similar way to the Carnegie-Mellon University version developed by Daneman and Carpenter[13] and to be sensitive to individual differences.[31,32] As shown in Fig 1, this task required that participants read aloud sets of sentences and remember a target word (written and underlined in red ink) in each sentence. After reading aloud the last sentence of each set, the participants were asked to recall the series of target words. The number of sentences in a set (ie, set size) increased over time from 1 to 5 sentences. Each sentence set size was presented in 5 trials, but with different sentences comprising the set in each trial. All participants completed the 5 trials for each set size. In terms of performance, we evaluated the proportion of words, which was the average proportional recall in each sentence condition, and the span score, which was the highest level at which a

1. The capital of Japan is Tokyo.
2. They practice singing every day.
3. There are some small parks in this city.
4. We encounter various problems every day.
5. The child dropped food on his jacket and made a stain.

Answers: "capital," "every day," "parks," "problems," "stain."

Figure 1. Sample sentences for the reading span test: The participants read 5 sentences loudly and memorized the words that were written and underlined in red ink.