# Performance of manual dexterity is deteriorated by acute experimental pain when performed in a combination with a demanding cognitive task

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*The aim of this study was to investigate the effects of acute pain on performance of a manual dexterity task completed alone or a combination with a demanding cognitive task. Performance of the manual dexterity task was measured as the time to complete a grooved pegboard task and the times to manipulate each peg during the selection, transport, insertion, and return phases. Twenty-two young adults (24.1 ± 2.0 years) went through a crossover design, where every participant underwent each condition in a randomized order. The grooved pegboard task was used to evaluate whether simultaneously providing; nothing (Peg), pain (PegPain), a cognitive interference task (PegSub), or a combination of both (PegPainSub) would affect pegboard performance. The cognitive task consisted of continuous subtractions of seven. No differences in pegboard completion time between Peg and PegPain was found. A longer completion time for PegSub and PegPainSub was found compared to Peg and PegPain. PegPainSub had longer pegboard completion times compared to PegSub. This was accounted primary by a longer selection phase duration for PegPainSub compared to PegSub. The results suggest pain had an interfered effect in completion time in a combination with the cognitive interference task compared to no pain. Furthermore, these results revealed that acute pain reduced performance on a manual dexterity task only in a combination with a cognitive task.*

Keywords: Manual dexterity - Acute pain - Grooved Pegboard - Interference Task - Attention

## Introduction

The effect of experimentally induced pain can shift attention to pain and away from other cognitively demanding tasks (Eccleston *et al.*, 1997; Moore, Keogh and Eccleston, 2012; Keogh *et al.*, 2013; Moore, Eccleston and Keogh, 2017). This change in attention known is an interference of pain often leading to a diminish in cognitive performance task (Eccleston *et al.*, 1997; Bu *et al.*, 2007; Moore, Keogh and Eccleston, 2012, 2013; Moore *et al.*, 2013; Keogh *et al.*, 2014; Moore, Eccleston and Keogh, 2017). Results suggest that this effect is most prominent in high demanding cognitive tasks (Keogh *et al.*, 2013; Moore and Law, 2017). High demanding cognitive tasks are often complex and require processing multiple cues to complete. Studies suggest that when performing a high cognitively demanding task, a greater proportion of processing capacity has to be allocated to the task in order to maintain an acceptable level of performance (Huang and Mercer, 2001). An essential research paradigm for investigating attentional processes is the implementation of a secondary task. This experimental paradigm is also called a dual task and can be considered to process more than one source of information simultaneously (Huang and Mercer, 2001; Moore, Eccleston and Keogh, 2017).

Processing capacity is limited and needs to be divided amongst on-going tasks (Laessoe *et al.*, 2008). When the available processing capacity is exceeded by the interference of a secondary task, an impaired performance in one or both tasks will occur (Laessoe *et al.*, 2008). This has been demonstrated by several dual task paradigms using two cognitive tasks (Della Sala *et al.*, 1995; Moore, Keogh and Eccleston, 2012; Moore, Eccleston and Keogh, 2017). Registration of pain will always demand some attention (Eccleston and Crombez, 1999). In experimental models, pain has proven its interruptive effects in single cognitive tasks (Keogh *et al.*, 2013) and even greater interruptive effects when doing high cognitive demanding tasks (Bu *et al.*, 2007;

Moore, Eccleston and Keogh, 2017) including dual tasks (Moore, Keogh and Eccleston, 2012; Keogh *et al.*, 2013, 2014).

In regards to dual tasks combining a motor task and a cognitive task, studies have investigated how an interference cognitive task would affect postural control (Woollacott and Shumway-Cook, 2002; Papegaaij *et al.*, 2017) and walking (Beauchet *et al.*, 2005; Laessoe *et al.*, 2008; Lamberg and Muratori, 2012; Brustio *et al.*, 2017). Findings of these dual task combinations have proven impaired cognitive (Laessoe *et al.*, 2008; Srygley *et al.*, 2009; Brustio *et al.*, 2017; Papegaaij *et al.*, 2017) and motor performances (Brustio *et al.*, 2017; Papegaaij *et al.*, 2017) relative to each of the tasks alone. These impairments of performance are suggested to occur due to exceeding the available processing capacity (Huang and Mercer, 2001; Laessoe *et al.*, 2008). Often, these dual task-studies investigating a motor-cognitive paradigm use an arithmetic subtraction task as their methodological assessment for adding cognitive demands (Laessoe *et al.*, 2008; Brustio *et al.*, 2017; Papegaaij *et al.*, 2017). However, in regard to the use of motor tasks to evaluate cognitive-motor dual task paradigm, it could be interesting to investigate which performance elements of the motor task are being affected by an interfering cognitive task.

Manual dexterity is a performance characteristic most often measured in the hand. Changes in manual dexterity can be quantified as the time it takes to complete a grooved pegboard test. The grooved pegboard test requires individuals to place 25 keyhole-shaped pegs into the board as quickly as possible (Almuklass *et al.*, 2017, 2018; Hamilton *et al.*, 2017). The grooved pegboard relies on decision making strategies (Hamilton *et al.*, 2018) and demands cognitive processing, in particular attention and executive function (Tolle *et al.*, 2019). Specific alterations in the performance of the grooved pegboard task has been tested by dividing the manipulation of each peg into four phases; (1) select one peg, (2) transport it to the specified hole, (3) insertion it into the hole and (4) return the hand back to the bowl to obtain another peg. The selection of a peg relies on tactile feedback and fine movement coordination (Thompson-Butel *et al.*, 2014). The transport phase likely relies on detecting and aligning the orientation of the peg to the hole (Thompson-Butel *et al.*, 2014; Almuklass *et al.*, 2017). It has only been investigated for older adults the transports phase seems related to cognitive functions (Ashendorf, Vanderslice-Barr and McCaffrey, 2009) including working memory (Hamilton *et al.*, 2017). On the behalf of these related findings, the transport phase likely is the most cognitively demanding phase. Insertion of the peg requires tactile and visuomotor coordination (Bryden and Roy, 2005; Wang *et al.*, 2011; Thompson-Butel *et al.*, 2014) for a successful rotation into the hole. All phases comprise of a rapid goal directed action; however, it is proposed to be more essential for the return phase (Almuklass *et al.*, 2018). Pegboard performance studies have found, persons with multiple sclerosis (Almuklass *et al.*, 2017) and healthy older adults (Almuklass *et al.*, 2018) were significantly slower than healthy young adults in all phases**.** Healthy middle-aged adults were only slower in the insertion phase than healthy young adults despite similar pegboard completion times (Almuklass *et al.*, 2018). For young adults, similar pegboard completion times was found with no affection of giving induced experimental pain (Smith, Pearce and Miles, 2006). However, no phase durations were investigated.

The purpose of this study was to investigate the effects of acute pain on performance of a manual dexterity task either alone or in a combination with a cognitive interference task. Performance of the manual dexterity task was measured as the time to complete the grooved pegboard and the times to manipulate pegs through the four distinct phases. We hypothesized a longer pegboard transport duration when introducing the cognitive interference task with pain, leading to an increase in pegboard completion time compared to no pain. Additionally, we evaluated performance of the cognitive interference task. Furthermore, we explored the forces applied during the insertion phase of the pegboard task to determine the relationship between force and force steadiness to the duration of the insertion phase.

## Method

*Participants*

Twenty-two subjects volunteered and completed the study. Male (N=12) and female (n=10) participants (mean ± standard deviation age: 24.1 ± 2.0 years; weight: 71.7 ± 13.7 kg; height: 176.0 ± 7.8 cm). Only two males were left handed as based on Edinburgh handedness inventory test (Oldfield, 1971).

Prior to the experiment, all participants completed a screening questionnaire to ensure a pain free status (Eccleston and Crombez, 1999) and no musculoskeletal disorders, hand or wrist injury, high experience with dexterity (e.g. playing piano), drugs or alcohol abuse (Almuklass *et al.*, 2018).

*Study Design*

The participants went through a crossover study design where all trials were assessed in a randomized order in one day. The study design consisted ten trials under six different conditions; two trials of grooved pegboard test (Peg), one trial of subtraction test (Sub), and two trials dual task consisting of the pegboard test and the subtraction test combined (PegSub). All of the protocol trials were completed without and with induced pain (PegPain, SubPain, PegPainSub) (See Figure 1). When performing the dual task, the subjects were instructed to prioritize each task equally. The participants completed the protocol with a one-minute pause between each trial (Almuklass *et al.*, 2018)

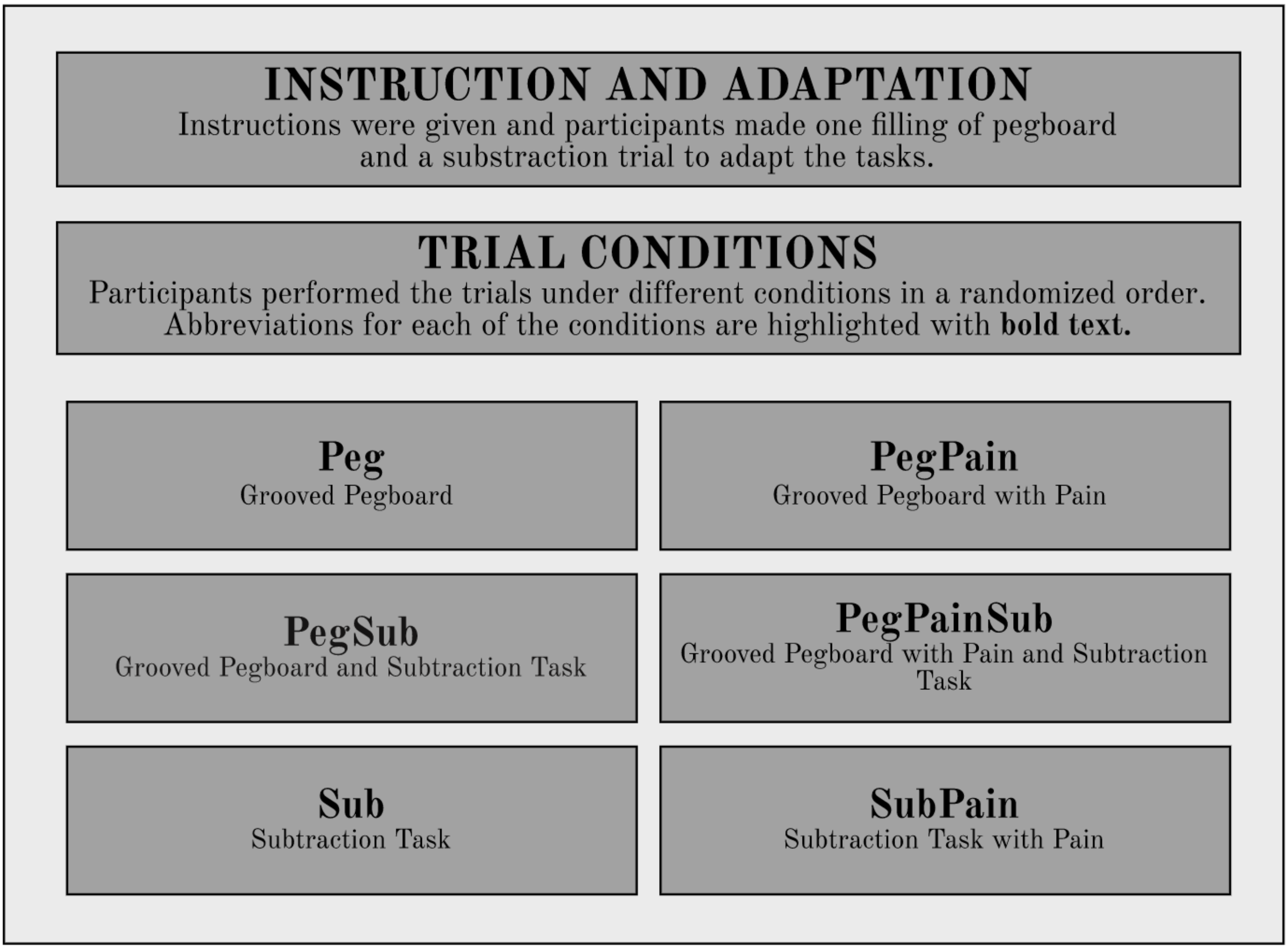


***Figure 1*** *- Illustration of the experimental design for all participants throughout the study.*

*Experimental Acute Pain Model*

Acute pain was induced using an inflatable blood pressure cuff (Everdixie - ZHE920) (see Figure 2) (Bank *et al.*, 2013). The cuff was inflated manually with a handheld sphygmomanometer bulb and then placed just below the participant's knee joint on their dominant side (see Figure 2). The knee joint was in a 90-degree angle. To assess pain intensity, participants were asked to rate when pain seven on a visual analogue scale (VAS) (0 = no pain, 10 = worst pain imaginable) before starting a pain conditioned test. After finishing every trial within a condition, the cuff was deflated, and the participants were asked to report an average pain intensity throughout the painful trial on a VAS. Prior to the onset of the next trial participants had to rate a pain intensity of zero. The one-minute break between each trial was sufficient to achieve a pain intensity rating of zero before starting the next trial for all participants.

***Figure 2*** *- The experimental setup for the motor task. The pressure cuff is clarified by a light grey frame. The cuff was placed just below the knee joint.*

*The Cognitive Interference Task and Performance Assessment*

The cognitive interference task was an arithmetic subtraction task. The task was started by a three-digit number (500-999) given by the lab leader. The participant spoke aloud serial subtractions of seven as many as possible in two minutes. If an incorrect subtraction occurred, the lab leader recited "wrong" and the most recent correct number was given. The purpose of providing a correction during the cognitive task was to ensure all participants were aware of getting feedback on correct subtractions.

Cognitive task performance assessment was measured as the correct amount of subtraction the participant spoke out loud during each trial. Only the correct subtractions were summed and used for analysis. The starting number was selected so the subtraction was not a part of the seven tabulation (0-100, fx. 570). Before performing the actual tests one adaption trial was given.

*Manual Dexterity Task*

A grooved pegboard (Model 32025; Lafayette Instrument Comp) consisting of 25 (5x5) aligned holes with a randomly positioned orientation (see Figure 3). Pegs, which had a key along one side, had to be rotated to match the hole before the peg could be inserted. For each trial, the subjects had two minutes to fill up and empty the board as many times as possible.

No reduction in cuff pressure were made when finishing one filling of the pegboard. This was facilitated so the participants would not be rewarded by becoming pain. When starting the pegboard test, every row had to be filled up from the non-dominant hand side to the dominant hand side starting from the top row. The subjects had to use their dominant hand. Emptying of the pegboard was done in reverse order (dominant side to non-dominant side starting from the bottom row) (Almuklass *et al.*, 2018).

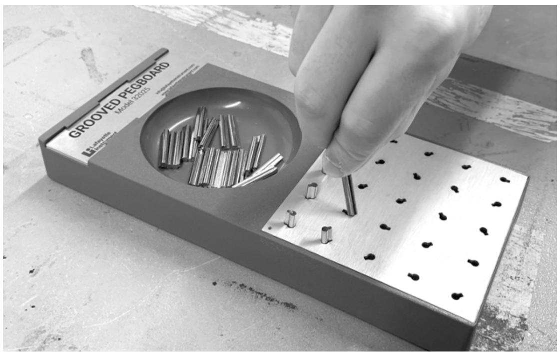


***Figure 3*** *- The design of the grooved pegboard.*

*Quantification of Manual Dexterity Performance*

The pegboard was placed on a force platform (Model OR6-7-1000; AMTI; Massachusetts; USA) which was connected to an amplifier (Model: MCA6 AMTI; Massachusetts; USA). Downward force was recorded with a custom made software (Mr. Kick, Knud Larsen, SMI, Aalborg University). From the downward forces, it was possible to determine four phases from each of the 25 peg manipulations. The four phases were: (1) select, (2) transport, (3) insert, and (4) return. An analogue trigger controlled by the same experimenter was connected to the software and was used to mark the beginning of the insert phase. Force data were sampled at 5 kHz and low-pass filtered (second-order bidirectional Butterworth filter) at 12 Hz.

*Data Analysis*

*Pain Intensity*

Mean cuff pressure and pain intensity ratings were calculated as the mean for each participant under each of the conditions where pain was included (SubPain, PegPain, PegPainSub) (n= 22).

*The Cognitive Interference Task*

The correct amount of subtractions was used for analysis, by calculating the average for each participant for every subtraction condition (Sub, SubPain, SubPeg, SubPegPain) (n=22). The test was video recorded (Nikon D5100) (included sound) to evaluate the time when participant recited subtractions with pegboard phase times.

*The Manual Dexterity Task*

*To* analyse pegboard times, phases times, forces and force steadiness a custom MatLab script (version 2017b, Mathworks, Natik, MA) was used. Phase times were calculated for pegs 2-4, 12-14 and 22-24 (Almuklass *et al.*, 2017, 2018) for a total of nine pegs per trial. If any random additional force deflection like a dropped peg occurred, the peg would be skipped, and the following peg analysed. The analysis was based on placing markers on a curve in a scatter diagram for time and force. Markers were manually placed at the beginning of each phase (see Figure 3). The trigger and video setup supported the identification of each peg insertion phase.

The onsets of the peg selection and insertion phases were identified when force (N) deviated away from zero for more than 100 ms. The insertion should be near by the trigger input. A phase was categorized as the transport or return phase if an offset of force was more than 100 ms (see Figure 4). The data for pegboard completion and phase times (peg 2-4, 12-14 and 22-24) were calculated as the mean of the two trials for each condition (Peg, PegPain, PegSub, PegPainSub) (n=22).

*Force and Force Steadiness*

The peak force for each trial was considered the mean of the highest detected force value during the insertion phase for pegs 2-4, 12-14 and 22-24. Forces steadiness was assessed by calculating the standard deviation from the nine peak forces (Almuklass *et al.*, 2018). Previous studies revealed that the standard deviation of force

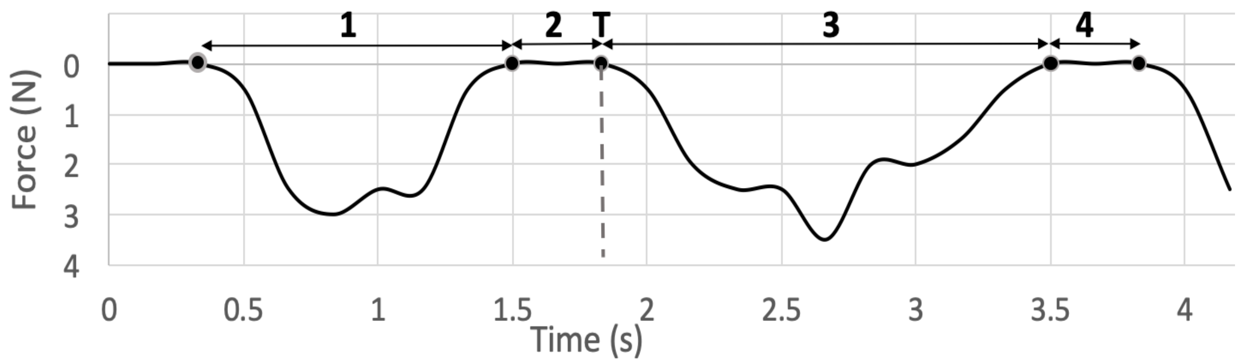


***Figure 4*** *- Example of analysis of force data. Black dots on the curve represent manually placed markers identifying the different phases. 1=selection phase, 2=transport phase, 3=insert phase and 4=return phase. T represents the trigger input.*

during peg insertion is an index of force steadiness (Marmon, Gould and Enoka, 2011; Almuklass *et al.*, 2016, 2017, 2018).

*Statistics*

All statistical analyses were conducted with SPSS statistics 24 (IBM Analytics, Armonk, NY, USA). The criterion for statistical significance was set at $P \leq 0.05$. P-values are reported in the text in the results section. All data were tested for normality using visual assessment of histograms and Q-Q plots. If sphericity could not be assumed, Greenhouse-Geisser corrected degrees of freedom were used.

A one-way repeated measures analysis of variance (ANOVA) was used to analyse differences in mean VAS pain ratings during SubPain, PegPain and PegPainSub. If a significant main effect was found a Bonferroni post hoc would be used.

The cuff-pressure data were not normally distributed. The examination was done with a nonparametric Friedman's test to compare cuff pressure differences within each pain condition (PegPain, SubPain, PegPainSub).

A one-way repeated measures analysis of variance (ANOVA) was used to analyse differences in the cognitive performance. To determine differences in manual dexterity for pegboard completion time were assessed using a one-way ANOVA. For differences in phase durations across pegboard conditions (Peg, PegPain, PegSub, PegPainSub) were compared with a two-way ANOVA, with pegboard conditions and phase (select, transport, insert and return) as the repeated measures factors.

To check for differences in peak force and force steadiness in the insertion phase two separate one-way ANOVAs was done.

Spearman correlations were used to assess the relation between the duration of the insertion phase with insertion force and insertion force steadiness. The mean from each trial was used for the correlations, giving two mean values for each pegboard condition (Peg, PegPain, PegSub, PegPainSub) per participant (n=44). All correlations were also inspected from a scatter plot.

**Results**

*Pain Intensity Ratings and Pressures*

There was no significant difference between pain intensity ratings as determined by the one-way ANOVA $F_{1.39,\ 29.10} = 2.90$, $p = 0.09$. Figure 5 shows the mean pain intensity ratings for PegPain (VAS = 5.1 ± 1.4), SubPain (VAS = 5.2 ± 1.5) and PegPainSub (VAS = 4.5 ± 1.7).

The Friedman's test revealed no significant differences in cuff pressure between PegPain (343.9 ± 89.5 mmHq), SubPain (357.5 ± 86.7 mmHq) and PegPainSub (345.1 ± 185.7 mmHq), $\chi 2_2 = 5.17$, $p = 0.08$ (see Figure 5).

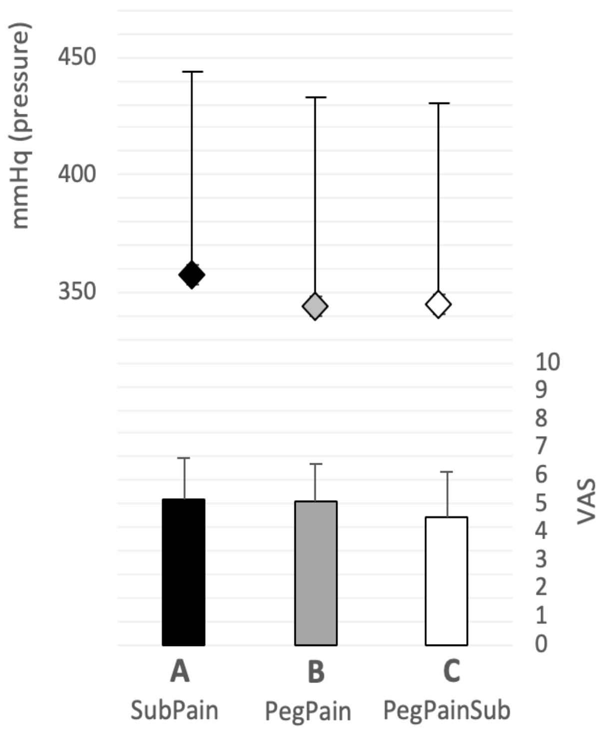


***Figure 5*** *- Showing mean cuff pressure and mean VAS for pain conditions: A=SubPain is coloured black, B=PegPain is coloured gray and C=PegPainSub is coloured white. No significant differences were found.*

*The Cognitive Interference Task*

The one-way ANOVA revealed a main effect between conditions (Sub, SubPain, SubPeg, SubPegPain) $F_{1.94,\,40.73} = 47.03$, $p < 0.001$. The performance for each condition was as followed (mean ± SD): Sub (42.2 ±17.0), SubPain (37.4 ±16.9), SubPeg (31.8 ±14.4) and SubPegPain (27.2. ±11.1). As shown on Figure 6 the post-hoc revealed a higher amount of correct subtractions during Sub was found compared to SubPain ($p < 0.001$), SubPeg ($p < 0.001$), SubPegPain ($p < 0.001$). For SubPain a higher amount of correct subtractions was found compared to SubPeg ($p < 0.01$) and SubPegPain ($p < 0.01$). Finally, a higher amount of correct subtraction was found for SubPeg compared to SubPegPain ($p < 0.01$).

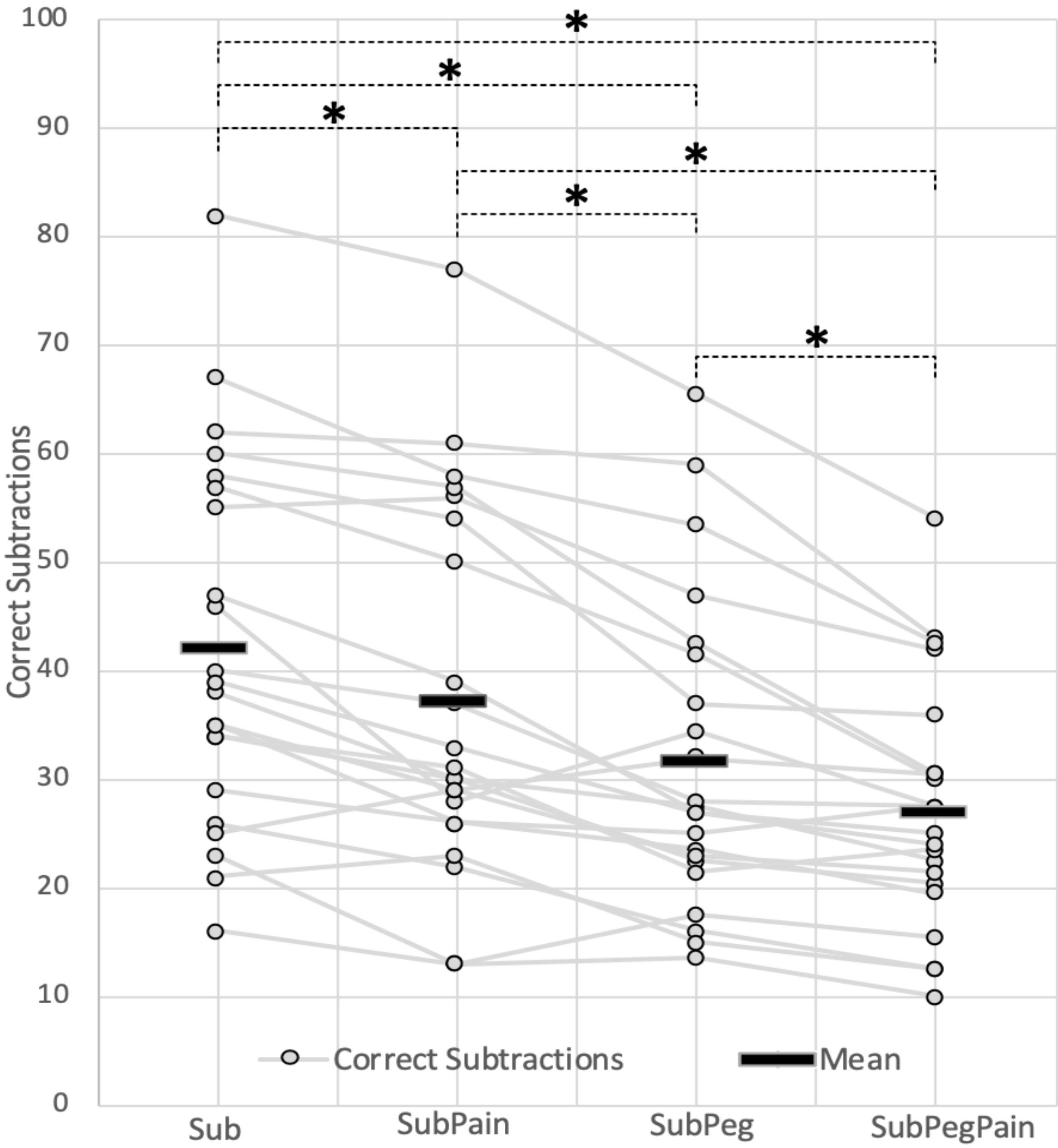


***Figure 6 -*** *Illustrates each participants' mean number of correct answers in the subtraction test under the different conditions (Sub, SubPain, SubPeg and SubPegPain). For each participant, a grey line connects each correct amount of subtractions for the four conditions. The mean value across participants for each condition is represented with a black bar. Significant differences are shown with asterisks (p < 0.05).*

*Pegboard Completions Times*

For pegboard completion times, the one-way ANOVA revealed a difference between conditions (Peg, PegPain, PegSub, PegPainSub) for pegboard completions times ($F_{1.40, 29.48} = 25.87$, $p < 0.001$). As shown in Table 1 and Figure 7, a faster completion time was found for Peg compared to PegSub ($p < 0.001$) and PegPainSub ($p < 0.001$). PegPain outperformed PegSub ($p < 0.001$) and PegPainSub ($p < 0.001$). Finally, PegSub outperformed PegPainSub ($p = 0.04$).

*Phase Times*

The two-way ANOVA revealed a significant pegboard condition by phase interaction, $F_{2.35,\ 49.38} = 5.13$, $p < 0.001$. Following the conditions by phase interaction, simple main effects were investigated by comparing pegboard conditions (Peg, PegPain, PegSub, PegPainSub) at each phase time (select, transport, insert, return). The Table 1 and Figure 8 shows, the post hoc analysis revealed a significantly longer peg selection phase for PegPainSub compared to Peg ($p < 0.01$) and PegSub ($p = 0.03$), a longer peg transport phase for PegPainSub compared to Peg ($p = 0.02$) and PegPain ($p = 0.01$), and a longer transport phase for PegSub compared to Peg ($p < 0.01$) and PegPain ($p < 0.01$). A longer return phase occurred for PegSub ($p = 0.01$) and PegPainSub ($p = 0.02$) compared to Peg. Video observation showed that participants often stopped the movement of the peg in the transport phase just before inserting the peg. This was mostly observed for PegSub and PegPainSub.

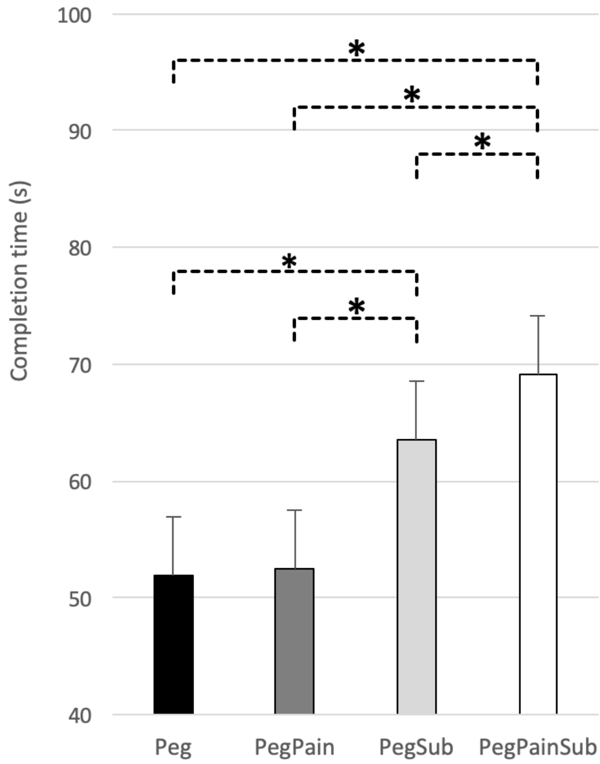


***Figure 7*** *- Overall completion time for the pegboard test. Significant differences are shown with asterisks (p < 0.05).*

| | *Pegboard time (s)* | *Select (s)* | *Transport (s)* | *Insert (s)* | *Return (s)* | *Force (N)* | *SD Force (N)* |
|---|---|---|---|---|---|---|---|
| *Peg* | *51.90 ± 7.39* | *0.43 ± 0.11* | *0.55 ± 0.10* | *0.81 ± 0.16* | *0.30 ± 0.06* | *1.96 ± 0.88* | *0.47 ± 0.22* |
| *PegPain* | *52.54 ± 7.58* | *0.47 ± 0.15* | *0.54 ± 0.12* | *0.81 ± 0.17* | *0.31 ± 0.07* | *1.83± 0.97* | *0.49 ± 0.25* |
| *PegSub* | *63.55 ± 11.26***Δ**†* | *0.48 ± 0.92***Δ** | *0.77 ± 0.24***Δ**†* | *0.84 ± 0.20* | *0.39 ± 0.13***Δ** | *1.69 ± 0.88* | *0.45 ± 0.20* |
| *PegPain-Sub* | *69.16 ± 15.74***Δ**†◊* | *0.54 ± 0.11***Δ◊** | *0.91 ± 0.49***Δ**†* | *0.92 ± 0.27* | *0.42 ± 0.20***Δ** | *1.63 ± 0.93* | *0.41 ± 0.19* |

***Table 1*** *- Presents pegboard completion times (mean time ± SD), phase times (mean time ± SD), peak force (mean force ± SD) and force SD (mean SD force ± SD). Significant differences are illustrated by the following symbols: Peg (Δ), PegPain (†) and PegSub ( ◊).*

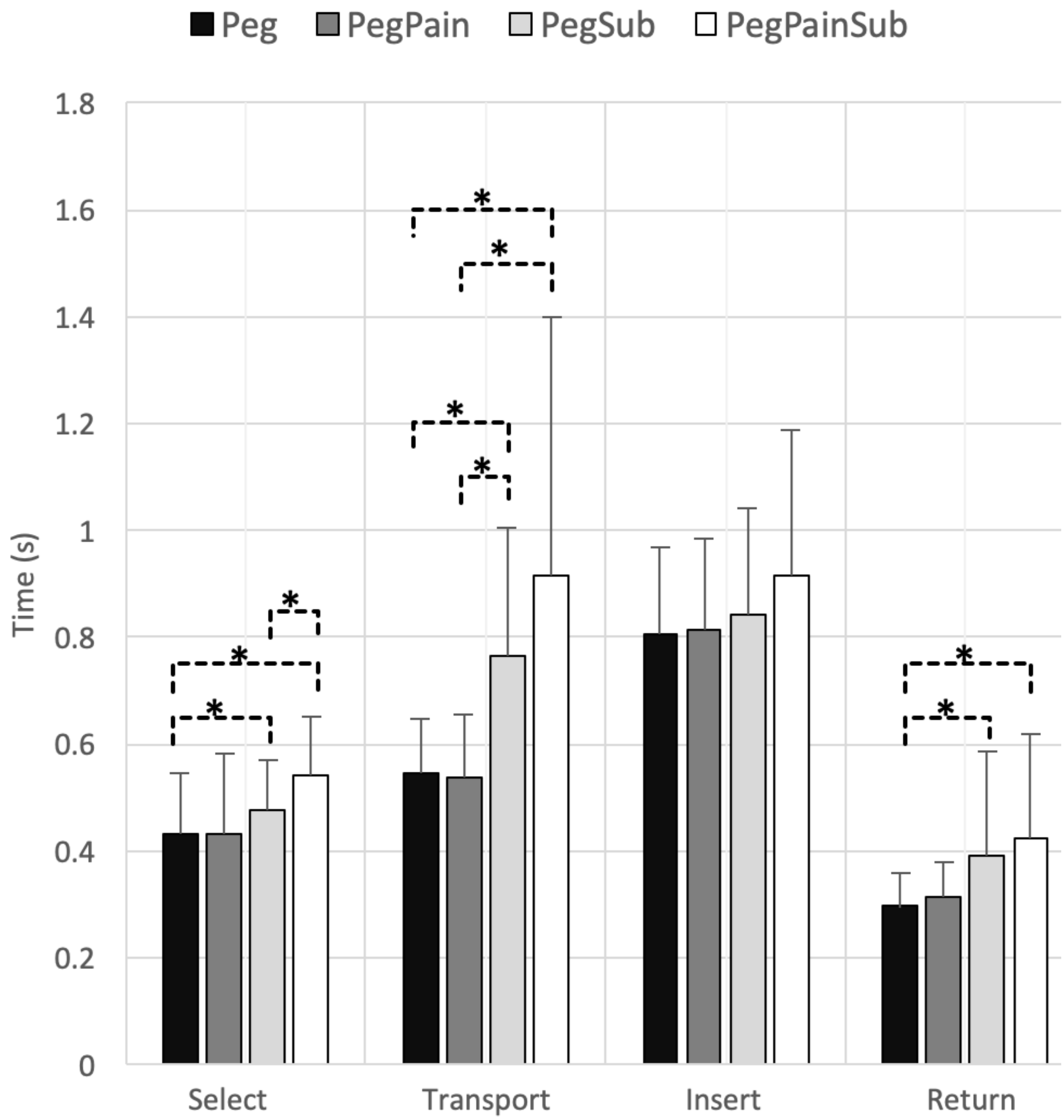


***Figure 8*** *- Mean phase times for each condition. Error bars represent standard deviation. Significant differences are illustrated with asterisks.*

*Force during Peg Insertion Phase*
The one-way ANOVA revealed no significant differences between pegboard conditions (Peg, PegPain, PegSub, PegPainSub) for mean peak insertion force, $F_{2.47,\,49.38} = 1.56$, $p = 0.22$ during peg insertion. For Force SD, a significant difference between pegboard conditions (Peg, PegPain, PegSub, PegPainSub) for mean peak insertion force SD was found, $F_{2.27,\,45.46} = 4.14$, $p = 0.02$. Only a higher force SD for PegSub compared to PegPainSub ($p = 0.04$) was found.
There was a significant correlation between insertion time and the peak insertion force for PegPainSub condition ($r = 0.35$, $p = 0.03$). No other correlations for mean insertion force and insertion time was found. Only a significant correlation between insertion time and force SD for PegSub was found ($r = 0.32$, $p = 0.05$).

**Discussion**
This study aimed to investigate the effects of acute pain on the performance of a manual dexterity task performed alone or in a combination with a cognitive interference task. Acute pain did not alter pegboard completion time. A longer pegboard

completion time was found performed in combination with a cognitive interference task. Finally, it was found that pegboard completion time was extended further when performed in combination with acute pain and cognitive interference task. This was primarily the result of a longer selection phase.

*The Influence of Pain on Manual Dexterity in a Combination with a Cognitive Interference Task*

This study is the first to investigate the influence of acute pain in a dual task paradigm using a motor and a cognitive task. Dual tasks are designed such that participants process more than one source of information simultaneously (Moore, Eccleston and Keogh, 2017). When performing dual tasks, the capacity to process essential information may be exceeded by performing the secondary task. This will lead to an impaired performance in one or both tasks (Huang and Mercer, 2001). The introduction of pain in this study was to assess the additional attentional demands when performing the pegboard and cognitive tasks simultaneously. The interruptive effect of pain is inescapable and will always emerge over other demands for attentions (Eccleston and Crombez, 1999). The longer completion times when applying pain in combination with a cognitive interference task might occur due to less available capacity to process essential information for completion of the pegboard task.

Other studies have investigated the influence of experimental pain in a dual task setting using two cognitively demanding tasks showing contradictory findings in performance. For example, induced thermal pain affected the most cognitively demanding tasks, including a dual task (Moore, Keogh and Eccleston, 2012). This suggest that high cognitive demanding task, particular executive control, are mostly impaired by the interference of pain (Bu *et al.*, 2007; Moore, Keogh and Eccleston, 2012; Keogh *et al.*, 2013, 2014). Our finding of a longer pegboard completion times for PegPainSub compared PegSub can therefore support this finding and interpretation. On the contrary, it has also been found in a dual task setup that induced pain had no affection on performance on working memory (Moore, Eccleston and Keogh, 2017). Suggestions have been that the type of attentional requirement of tasks (Lavie, Hirst and Fockert, 2004; Legrain *et al.*, 2011) and the cognitive task load (Legrain *et al.*, 2011; Moore, Eccleston and Keogh, 2017) influence the contradictory findings (Moore, Eccleston and Keogh, 2017). Limitations of studies have been that participants report a lowering pain intensity rating when performing high cognitively demanding tasks compared to a low demanding task (Lavie, Hirst and Fockert, 2004; Legrain *et al.*, 2011), especially when high perceptual demandings is required for completion of the tasks by decreasing the distractor interference by reducing the perceived pain suggested by Lavie *et al.,* (2011). However, during the pain conditions in our study, no pain intensity differences were found between the reported pain intensity ratings when initially being induced with a pain intensity of seven on the VAS. This was also verified by the result that the cuff inflation pressure for inducing a pain intensity of seven did not differ between pain conditions. The pain model used in this study was therefore sound.

Studies combining a motor and a cognitive interference task found deteriorated motor performance (Woollacott and Shumway-Cook, 2002; Laessoe *et al.*, 2008; Papegaaij *et al.*, 2017). For example, walking combined with talking on the phone decreased walking speed and accuracy (Lamberg and Muratori, 2012). A more complex set up involved participants texting led to additional decreases in walking performance (Lamberg and Muratori, 2012). Our results indicate the same impaired motor performance results in without pain dual task design. Most studies suggest that an exceeding of the processing capacity occurs as too many multiple sources of information was to be processed (Huang and Mercer, 2001; Woollacott and Shumway-Cook, 2002; Laessoe *et al.*, 2008; Papegaaij *et al.*, 2017). This argumentation is might supported by fMRI-results, showing a decreased activity in essential brain areas for cognitive processing during a balance and cognitive dual task compared to during the balance test alone (Rosso *et al.*, 2017).

However, this study does not determine any performance output of the tasks or relations to the decreased brain areas.

We utilized phase times to investigate specific alterations of pegboard performances between conditions. A longer selection duration was found for PegPainSub compared to PegSub. This suggests that pain in a combination with a cognitive interference task interrupts the picking of the peg. The selection of a peg has been shown to rely on tactile feedback and fine movement coordination (Thompson-Butel *et al.*, 2014; Almuklass *et al.*, 2018). This indicates that pain might have an interruptive effect on processing essential tactile feedback and / or movement coordination in order to select a peg. However, this relationship with pain is only in a combination with secondary cognitive demanding task since no difference in selection phase was found when performing the pegboard task alone. For young adults, the primary determinants of grooved pegboard time have been suggested to be indices of decision-making strategies related to the speed accuracy trade-off (Almuklass *et al.*, 2016, 2017, 2018; Hamilton *et al.*, 2018). Since a slower selection duration for PegPainSub compared to PegSub occurred, this interruptive effect of pain and an interference task might influence these primary determinants suggested with performance the pegboard alone with no pain. However, the completion of the pegboard assesses a range of psychomotor abilities, including cognitive acuity, tactile sensation, muscle strength, and force control (Thompson-Butel *et al.*, 2014; Almuklass *et al.*, 2017; Tolle *et al.*, 2019). Therefore, some of these abilities might be more interfered with pain.

No difference was found for the transport phase between PegPainSub and PegSub negating our hypothesis. This was based on previous findings of relations between the transport phase and cognitive functions for older adults (Ashendorf, Vanderslice-Barr and McCaffrey, 2009; Hamilton *et al.*, 2017). For example, the time to complete the full pegboard and scores on tests of memory, attention and executive function (Hamilton *et al.*, 2017). Giving these findings of the transport phases, it may comprise of high-order of attention processing. An exceedment of the processing capacity might occur due to the cognitive demands of the interference task and transport phase. This was not a sufficient interruption leading to a longer transport phase time for PegPainSub compared to PegSub. For PegPainSub, a large amount of performance variability for the transport durations occurred. This variability underscores that the processing capacity is individually affected (Woollacott and Shumway-Cook, 2002). Furthermore, the detrimental effect of pain depends on motor performance (Hodges and Tucker, 2011; Bank *et al.*, 2013), the type of motor task, type of pain and characteristic of participants (Hodges and Tucker 2011; Graven-Nielsen and Arendt-Nielsen 2008). The findings of phases times underscore the sensitivity and necessity of quantifying the times for each of the four phases separately.

Video observation showed an interesting relationship between the timing of manipulate each peg and when the subtraction answer was given by the participants (data not reported). Often, participants stopped the movement of the peg in the transport phase just before inserting the peg in order to be able to complete the subtractions. This was mostly observed for PegSub and PegPainSub. This observation supports the idea that the distribution of attentional processing has to be shifted in order to successfully complete one of the two tasks. Further, this also reflects a commonly adopted strategy to manage pain.

We evaluated the forces applied during the insertion phase of the pegboard task and their relationship to insertion phase duration. Studies have found that pain can change movement coordination (Graven-Nielsen and Arendt-Nielsen, 2008) and change force steadiness (Bandholm *et al.*, 2008). Our results could not confirm this.

*The Influence of Pain on Manual Dexterity*

The pegboard completion times for the young adults in this present study without induced pain or an interference task were consistent with other studies (Ruff and Parker, 1993; Bowden and McNulty, 2013; Almuklass *et al.*, 2016, 2018). Acute pain had no effect on the time to complete the pegboard compared to no pain, which aligns with previous findings using acute remote hand pain (Smith, Pearce and Miles, 2006). However, a longer pegboard completion time and reduced dexterity have been found for patients with musculoskeletal chronic pain (Gunnarsson, Grahn and Agerström, 2016) and pain arising from arthritis (van Lankveld, van 't Pad Bosch and van de Putte, 1998) compared to healthy controls. These contradictory findings illustrate the complexity of the affection of pain and underscore the sensitivity of depending factors such as experimental pain versus real life pain, type of pain, location of pain and task and characteristic of participants (Eccleston, 1995; Hodges and Tucker, 2011; Bank *et al.*, 2013).

Motor performance is the result of an interaction among cognitive, perceptual, mechanical, and neurological mechanisms (Huang and Mercer, 2001). The idea of implementing pain was to evaluate the influence of cognitive interaction by the deterioration of acute pain on attention. The influence of pain on the amount of attention may differ depending on type of pain and demands from the giving task/tasks. Taking the limited processing capacity into account, the capacity may not be exceeded or affected by the acute pain when performing the pegboard, resulting in no inhibition of performance.

Our phase times with no pain are similar to other finding from previous studies for young adults (Almuklass *et al.*, 2018). Inspecting the phase times comparing PegPain to Peg, pain did not result in a slower time for any of the phases. As mentioned, a difference in selection phase time occurred when induced pain was giving in a combination with pegboard and an interference task. Therefore, the affections of pain might be increased the greater amount of capacity that are processed.

No differences were found for mean peak insertion forces during peg insertion for Peg and PegPain. No correlations for mean insertion force and insertion time was found.

*Performance of the Cognitive Interference Task*

The amount of correct subtractions for SubPain, SubPeg and SubPegPain were less compared to the relative single-task reference without pain (Sub). Further, lower performance scores were found for SubPeg compared to SubPain, and SubPegPain compared to SubPeg. This finding might illustrate a ranking of a greater amount of processing capacity were allocated must when performing (1) pain condition in a combination of pegboard and subtraction, (2) pegboard and subtraction and (3) subtraction in a pain condition. Experimental pain has been proven to diminish cognitive performance (Moore, Keogh and Eccleston, 2012; Bank *et al.*, 2013; Attridge *et al.*, 2015). Other dual tasks using a motor task and the subtraction task without pain has also found impaired subtraction performance scores compared to the relative single-task reference (Laessoe *et al.*, 2008; Srygley *et al.*, 2009; Brustio *et al.*, 2017). The fewer amount of subtraction relative to single-task performance in this study are therefore consistent with other findings. However, the characteristics of the cognitive task should be considered carefully when designing and comparing dual task performance (Beauchet *et al.*, 2005; Laessoe *et al.*, 2008). This study is the first to evaluate the cognitive interference performance in a combination with a motor task under painful stimuli. The lowered performance scores for the subtraction test with pain compared to without indicates that pain further facilitates a performance impairment. Pain will always demand some attention (Eccleston and Crombez, 1999) which could otherwise be allocated to process of the subtraction test. The subtraction task does not demand any limb movement that influences the completion of pegboard. By this method, the interference of attentional capacity is more likely to be evaluated.

There might have been some learning effect in relation to the subtraction test. This was taken into account by randomizing the order of the conditions. In both the grooved pegboard completion time and the subtraction task, no differences in the order of task assessment were found (data not reported). Furthermore, the relative changes of the subtraction and pegboard performance indicate that the participants did not prioritize one task exclusively.

*Perspective*

Our data present impaired manual dexterity when performing a cognitive interference task with and without pain. This provides important information for physical therapists making clinical assessments and intervention strategies (Huang and Mercer, 2001). For example, patients are frequently given information in rehabilitation settings where patients have to relate or even recall instructions, medication schedules and training plans. Impaired performance and/or alterations in motor performance can affect motor strategy and consolidation (Bank *et al.*, 2013).

Chronic or naturally occurring pain has a threat value and likely affects different qualities than in a controllable environment (Edens and Gil, 1995; Moore, Eccleston and Keogh, 2017) Therefore, it is necessary to investigate whether similar or even a greater pain-interference effects would occur with naturally occurring pain.

## Conclusion

In conclusion, pegboard completion time was extended further when performed in combination with acute pain and cognitive interference task compared to no pain. This was accounted primary by a longer selection phase duration. Acute pain did not alter pegboard task completion time. A longer pegboard completion time was found performed in combination with a cognitive interference task. A recurring suggestion throughout this study is the affections of pain might be increased the greater amount of attentional capacity that are processed.

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