

# Exploring how different protocols of noxious electrical stimulation differentially modulate performance in two isometric strength-endurance tasks

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## Abstract

*Introduction:* When the human body is exposed to noxious stimuli, nociceptors activate and send signals to the brain, which may be perceived as painful. Experimental pain has shown different influences on motor performance. During exhausting exercise acute muscle soreness (AMS) will occur caused by inadequate blood flow to the working muscles and may result in a withdrawal from the task. Electrical stimulation (ES) can increase blood flow to the working muscles and may be used to direct attention away from AMS. The present study aims to investigate the influence of two different noxious ES protocols in isometric strength-endurance performance in a wall squat and hand grip task measured in time to exhaustion (TTE). *Methods:* A randomised crossover study with three sessions will be conducted with a different protocol for each of the three sessions: 1) No induced noxious electrical stimuli (No-Pain), 2) intermittent noxious electrical stimuli delivered throughout the task (Throughout-Pain), 3) intermittent noxious electrical stimuli initiated at the occurrence of AMS (AMS-Pain). Participants (n=34) will undergo all three sessions, which will be conducted with a minimum of 72 hours between each session. *Results:* Significant increases in wall squat performance in AMS-Pain compared to No-Pain ( $P<0.01$ ) and Throughout-Pain ( $P<0.01$ ) are found, yet no difference in performance is found between No-Pain and Throughout-Pain ( $P>0.99$ ). Significant increases in hand grip performance are found in Throughout-Pain ( $P<0.01$ ) and AMS-Pain ( $P<0.01$ ) compared to No-Pain. However, a greater increase is found in AMS-Pain compared to Throughout-Pain ( $P=0.01$ ). *Discussion:* The greatest improvement in performance is observed in AMS-Pain. This indicates that noxious ES may create favourable physiological advantages for isometric strength-endurance performance, and possibly oppose the physiological influences of AMS. The findings from the present study show that it may be both protocol and task dependent whether noxious ES facilitates or has no influence on performance. *Conclusion:* Initiating ES at AMS occurrence has a greater improvement in isometric strength-endurance performance compared to no electrical stimuli or stimuli delivered throughout the task.

## Keywords

acute muscle soreness, performance, noxious electrical stimulation, isometric strength-endurance.

## **Considerations regarding COVID-19**

Due to social distancing requirements during the COVID-19 pandemic laboratories were closed, and conducting the experiment was not possible. However, pilot testing was conducted both before and after lockdown, where the data collected after lockdown were collected while still managing social distances. An e-familiarisation of the wall squat task was implemented to collect genuine data despite social distancing. However, the main data from the experiment were mock data created by the supervisors. Due to these circumstances, the present study focuses on the experimental design, statistics, interpretation of the mock data relative to previous studies, and perspectives. In particular, the perspective section is expanded, and the application of the concepts introduced in the present study are explored more deeply with an emphasis on development and application of an innovating device for improving performance.

## **Introduction**

When the human body is exposed to noxious stimuli, nociceptors activate and send signals from the periphery through the spinal cord to the brain, which may be perceived as painful (Patel, 2010). Nociceptors can be activated by algogenic substances and noxious mechanical, thermal or electrical stimuli (Hudson, 2000). Noxious stimuli can lead to an activation of the sympathetic nervous system (SNS) resulting in increased alertness, breathing, heart rate (HR) and oxygen uptake (Milosevic, 2015; Watanabe et al., 2014). This activation of the SNS is also observed in experimental pain studies using electrical stimulation (ES), skin cooling or heat stimuli, where a marked increase in HR is found (Watanabe et al., 2014; Kregel et al., 1992; Loggia et al., 2011). An increase in HR may result in an increased blood flow to the working muscles, thus improving motor performance (Shephard, 2000).

Experimental pain induced by hypertonic saline injection into muscles has shown reduced motor performance in gross movements in humans such as decreased force-steadiness, muscle activation and strength (Rice et al., 2015; Bandholm et al., 2008; Henriksen et al., 2007; Henriksen et al., 2011). In contrast, some studies show that experimental pain, induced by either ES or capsaicin cream, facilitates gross or fine motor performance respectively in humans, where increased swimming performance (Girolid et al., 2012), increased ice-skating performance (Brocherie et al., 2005), increased accuracy (Dancey et al., 2014; Dancey et al., 2016), and decreased reaction time (Dancey et al., 2014) are observed. The differing responses in performance to experimental pain may be caused by the source of the pain, as it is suggested that deep muscle and cutaneous pain may trigger different responses in the nervous system (Keay & Bandler, 2002). Deep muscle pain can occur during exhausting exercise such as strength-endurance tasks, as acute muscle soreness (AMS) will develop and cause a painful sensation (Abraham, 1979). AMS activates the afferent A $\delta$  and C fibres (Bigland-Ritchie et al., 1992) thus facilitating the occurrence of central fatigue (Laurin et al., 2015) resulting in limited motor performance (Shephard, 2000). Cutaneous pain can lead to increased blood flow (Keay & Bandler,

2002), and facilitate motor performance (Rush et al., 2000; Shephard, 2000), which can be induced by ES (Riley et al., 1998).

Motor performance may be influenced by the athlete's ability to overcome or tolerate pain (Mauger, 2013). When pain is developed during exercise it is often perceived as damaging (Dannecker & Koltyn, 2014), which can diminish physical activity (Hirsh et al., 2008; Leeuw et al., 2007). If the motivation to persist performing is reduced it facilitates the occurrence of central fatigue, yet central fatigue will eventually occur even though the athlete is fully motivated to proceed performing (Davis & Bailey, 1997). Furthermore, when pain occurs during a task attention will often be directed towards the pain, even though it is not relevant for the specific task (Van Damme et al., 2010). Therefore, it can be favourable to use noxious ES to divert attention away from the AMS arising during exercise (Ingham et al., 2011; Passmore et al., 2014) to possibly overcome the urge to withdraw from the task and thus improve strength-endurance performance.

To our knowledge, no studies have investigated the influence of noxious ES during an isometric strength-endurance task. ES is easily implemented in sport contexts (O'Connor & Cook, 1999), and therefore provides the opportunity to induce pain during motor performance, which may contribute to an improvement in motor performance by activating the SNS and thus opposing the physiological influences caused by AMS. Furthermore, noxious ES may act as a diverted focus to AMS resulting in a facilitation of motor performance. Further research is needed to apply this knowledge in sport contexts, as it may be used as a tool to improve strength-endurance performance. The purpose of the present study is therefore to investigate the influence of noxious ES on isometric strength-endurance performance during a wall squat and hand grip task measured in time to exhaustion (TTE). Moreover, the aims are to explore two different pain protocols where noxious electrical stimuli are delivered intermittent either initially and throughout the task (Throughout-Pain) or initiated when AMS occurs and throughout the task (AMS-Pain). It is hypothesised that noxious ES will improve isometric strength-endurance performance with an increased TTE in the wall squat and hand grip tasks in both pain protocols compared to a no pain control, yet a greater improvement will be observed in AMS-Pain.

## **Methods**

### **Participants**

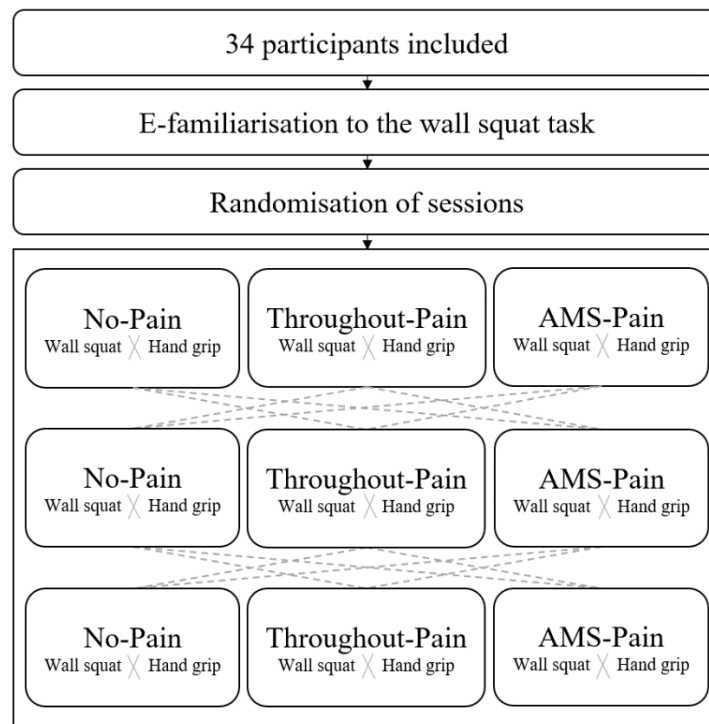
A priori power test (G\*power) with a medium effect size of 0.25 and a power of 0.8 was conducted, which was based on a study with a similar design as the present study (Hübscher et al., 2010). The power test revealed that 28 healthy adults were sufficient to reach a power of 0.8. However, to account for a dropout rate of 20 %, 34 participants will be included. The target group for the present study are trained individuals, and participants must therefore fulfil the World Health Organization's recommended levels of physical activity (World Health Organization, n.d.) to be recruited. To determine the participants' dominant hand for the hand grip task the Edinburgh Handedness Inventory

(Oldfield, 1971) will be used. All participants will provide signed written informed consent before participating, and must be pain free in all regions of the body before each session.

### Study design

Due to the COVID-19 pandemic the experiment was not conducted and the data, except for the e-familiarisation data, in the present study are mock data created by the supervisors.

Before conducting the experiment, 17 participants were e-familiarised to the wall squat task. The experiment will be designed as a crossover study with three sessions (Figure 1) to explore how different pain protocols influence isometric strength-endurance performance. During each session the participants (n=34) will conduct two isometric strength-endurance tasks; wall squat and hand grip until TTE, in a randomised order. Different protocols will be used for each of the three sessions: 1) No induced noxious electrical stimuli (No-Pain), 2) intermittent noxious electrical stimuli delivered throughout the task (Throughout-Pain), 3) intermittent noxious electrical stimuli initiated at the occurrence of AMS (AMS-Pain). Participants will undergo all three sessions lasting approximately 30 minutes each with a minimum of 72 hours rest between each session. Furthermore, the sessions will be conducted at approximately the same time of the day ( $\pm 2$  hours) as individual circadian rhythms can influence physical performance caused by a hormonal change in cortisol and testosterone (Teo et al., 2011).



**Figure 1 - Study design.** The study design includes three randomised sessions, where each participant will perform two isometric strength-endurance tasks: Wall squat and hand grip. Initially, the participants will be e-familiarised to the wall squat task. Different protocols will be used for each of the three sessions: No induced noxious electrical stimuli (No-Pain), intermittent noxious electrical stimuli delivered throughout the task

*(Throughout-Pain), intermittent noxious electrical stimuli initiated at the occurrence of acute muscle soreness (AMS-Pain). Participants will undergo all three sessions conducted with a minimum of 72 hours between each session.*

### **E-familiarisation**

Seventeen participants (8 males, 9 females, age  $25.9 \pm 2.3$  years) conducted an e-familiarisation of the wall squat task. The e-familiarisation consisted of three sessions each containing a wall squat task performed to TTE with a minimum of 72 hours between each session. The participants received electronic written and graphic instructions on how to perform the wall squat task. Furthermore, participants were asked to report the time for AMS and TTE occurrence in each session. The purpose of the e-familiarisation was to familiarise the participants to the task and minimise the learning effects in the main experiment. Any remaining learning is then counterbalanced by utilising the crossover design. Due to the need of special equipment it was not possible to conduct an e-familiarisation for the hand grip task.

### **Experimental protocol**

Prior to the experiment, the participants will be instructed not to do any physical activity 30 minutes before arriving to avoid elevated HR due to physical activity. The participants will initially be seated comfortably in a chair and instructed to relax while verbal instructions will be given regarding the purpose of the study. Furthermore, the participants will be informed whether they will receive no stimulation (No-Pain), stimulation randomly throughout the task (Throughout-Pain), or stimulation randomly initiated at a selected time point during the task (AMS-Pain), dependent on the session.

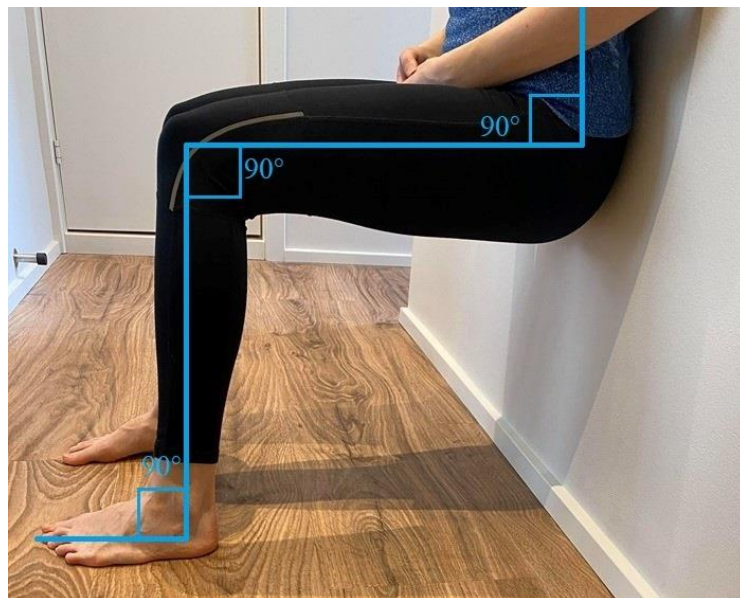
Two electrodes will be placed bilaterally on the participants' erector spinae muscles to induce noxious electrical stimuli. Moreover, a HR-monitor will be applied to measure HR before and during the wall squat and hand grip task, which will be recorded with a Suunto Ambit3 Run watch. This will be applied to measure how isometric strength-endurance tasks and noxious ES influences HR. The measured HR will be processed and grouped into four time points: When the participants were at rest (HR-resting), mean HR before the participants felt AMS (HR-beforeAMS), mean HR after the participants felt AMS (HR-duringAMS) and HR when the participants reach TTE (HR-TTE). To measure the participants' resting HR, they will be given 5 minutes rest with no interaction after the instructions and placement of the electrodes and HR-monitor.

The participants' pain threshold will be assessed by increasing the intensity of the electrical stimuli until the sensation of pain occurs. When the pain threshold is found the participants will be familiarised to the ES protocol by receiving three stimuli with 110% pain threshold. Afterwards, the participants will be asked to rate the pain from the electrical stimuli on a 0-10 numerical rating scale (NRS) (0 indicates no pain and 10 indicates worst imaginable pain) to assess the pain intensity. The isometric strength-endurance tasks will then be conducted. However, before initiating a task, the

participants' HR must be at a resting state. During the tasks, the participants will be instructed to report when they perceive a sensation of AMS (when the sensation in the quadriceps muscles changes from 'uncomfortable' to 'painful'). After each task, the participants must rate the pain from the latest received electrical stimulus on the NRS. No verbal encouragement will be given during the tasks to ensure consistency, due to the variation on how encouragement may be received (Andreacci et al., 2002; Guyatt et al., 1984).

### **Isometric strength-endurance tasks**

During the wall squat task, the participants must keep their backs against a wall, while their ankles, knees and hips are in a 90-degree angle with their arms resting on their thighs as shown in Figure 2. The wall squat position will be standardised for each participant, using tape as a marker to reposition the feet and head to the remaining sessions. Tape will be placed on the floor at the lateral and ventral side of each foot, and on the wall directly above the head for each participant. The participants will be asked to hold the position until TTE. TTE will be noted when participants cannot hold the correct position within 2 centimetres from the markings or withdraw from the task. A pillow will be placed on the floor below the participants to soften the fall if the participants collapse.



**Figure 2 - The correct position of the wall squat.** The position of a wall squat with the back against a wall, while ankles, knees and hips are in a 90-degree angle with arms resting on thighs.

For the hand grip task, a hand dynamometer (Constant, Model: 14192-709E) will be used. During the task the participants will be seated in a chair with their dominant elbow resting on a table in a 90-degree angle, and a supination in their wrist as shown in Figure 3. Initially, the participants will conduct three maximal voluntary contractions (MVC) with the hand dynamometer for three seconds with one minute rest between each MVC, where the highest value will be used as a reference. MVCs

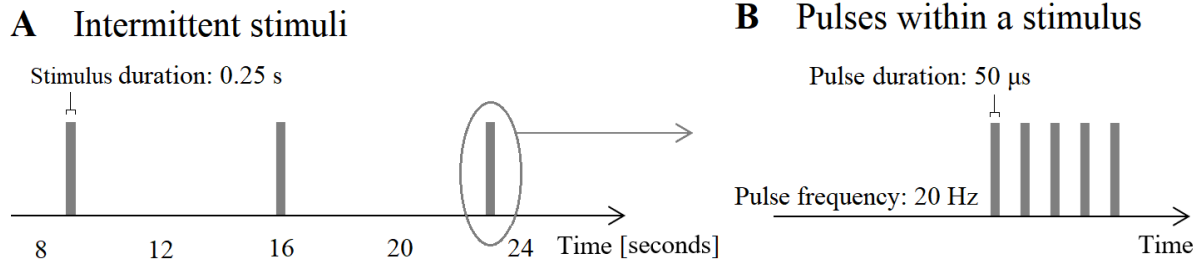
will be conducted in every session and verbal encouragement will be given. During the task, the participants must hold an isometric grip force within 25-30 % of MVC until TTE, where TTE is noted when the force has been below 25 % MVC for more than 2 seconds, or the participants withdraw from the task.



*Figure 3 - The correct position of the hand grip task. The arm position during the hand grip task with the elbow resting on a table in a 90-degree angle, and the wrist in a supination position.*

### **Electrical stimulation protocol and assessment of pain threshold**

Two electrodes will be placed bilaterally on the participants' erector spinae muscles in the Throughout-Pain and AMS-Pain sessions, while no electrodes will be used in the No-Pain session. One of the authors of the present study will be responsible for placing the electrodes to keep a high consistency of the electrode placement. The stimulation electrodes (32mm, PALS platinum plated conductive neurostimulation electrodes; Axelgaard Manufacturing, Fallbrook, CA) will be connected to a constant-current stimulator (DS5 Isolated Bipolar Constant Current Stimulator, Digitimer Ltd., UK) controlled by the labview software Mr.Kick (Mr.Kick III, Aalborg University, Denmark). The electrical stimuli consist of five 50  $\mu$ s square pulses, delivered at 20 Hz with an inter stimulus interval (ISI) of 8 seconds with a randomised variation of  $\pm 1$  second (Figure 4). The stimulation intensity will be set to 110 % pain threshold for each participant.



**Figure 4 - Electrical stimulation.** A) Intermittent electrical stimuli with an inter stimulus interval of  $8\pm 1$  seconds. B) Each stimulus consisting of five  $50\ \mu\text{s}$  square pulses, delivered at 20 Hz. The figure does not comply with correct size ratio.

The stimulation intensity of 110 % pain threshold is chosen as pilot testing showed marked fluctuations in the grip force-steadiness of the hand dynamometer at higher intensities for some of the participants. To assess pain threshold, stimuli can be delivered randomly with a small increase in stimulation intensity (Neziri et al., 2011). In the present study, the stimuli (five  $50\ \mu\text{s}$  square pulses, delivered at 20 Hz) will be delivered with an ISI of  $8\pm 1$  seconds starting at 2 mA and increased by 2 mA until pain threshold. Pain threshold is characterised as the lowest stimulation intensity that provokes a painful sensation (O'Connor & Cook 1999). Pain threshold can differ between sessions for each participant (O'Connor & Cook 1999) and will therefore be reassessed at both the Throughout-Pain and AMS-Pain sessions.

### Data analysis

The authors of the present study compiled excel-sheets outlined with headings and columns needed to be filled out in order to run the statistical analysis. Mock data in the present study were based on domain knowledge and data from pilot testing and e-familiarisation. Data from pilot testing consisted of the time for AMS and TTE occurrence in the hand grip ( $n=10$ ) and wall squat ( $n=8$ ) task, and HR measurements in both tasks ( $n=4$ ). The e-familiarisation data consisted of the time for AMS and TTE occurrence in the three wall squat tasks for each participant ( $n=17$ ). In the mock data the time points for AMS and TTE occurrence were noted for all participants in both the wall squat and hand grip task in all three sessions: No-Pain, Throughout-Pain and AMS-Pain. In both tasks and all three sessions HR was noted at the four time points: HR-resting, HR-beforeAMS, HR-duringAMS and HR-TTE.

Initially, outliers in TTE data were calculated in both the mock and e-familiarisation data. If a participant's TTE deviated from  $\text{mean}\pm 2\text{SD}$  (Jones, 2019) in a session in one of the tasks, the participant's performance and HR data for that specific task were excluded from further analysis. Three participants were excluded from the wall squat task, while two were excluded from the hand grip task. Furthermore, one participant's data were excluded from the e-familiarisation.



### **Statistical analysis**

IBM SPSS Statistics 25 was used to statistically analyse the mock and e-familiarisation data. Initially, Shapiro-Wilks tests were used to check for normal distribution in the TTE data in both the wall squat and hand grip task in all three sessions: No-Pain, Throughout-Pain and AMS-Pain. A normal distribution was found in TTE in both the wall squat and hand grip task in all three sessions. However, some of the HR data showed a non-normal distribution and were therefore log-transformed (LOG10). The LOG10 transformation did not normal distribute all data, and non-parametric tests were therefore conducted in the analysis of the HR data.

Analysis of variance (ANOVA) repeated measures within-factors were used to examine if a difference occurred in the participants' performance in TTE between the three sessions in both tasks. Furthermore, to examine the three e-familiarisation sessions for a potential learning effect an ANOVA repeated measures within-factors was conducted on the TTE data. Non-parametric Kruskal Wallis tests were conducted on the HR data to examine if significant differences occurred between the participants' HR in both tasks and all three sessions. To investigate if ES delivered throughout the task influenced the time for AMS occurrence, an independent t-test were conducted on the time for AMS occurrence between No-Pain and Throughout-Pain.

Generally, if a significant difference was found, a post-hoc test was conducted to examine where the difference occurred. In the post-hoc testing the Bonferroni corrected P-values for the pairwise comparisons were used. If the assumption of sphericity was not met Greenhouse-Geisser corrected p-values and degrees of freedom were used. The data were significant if  $\alpha \leq 0.05$ .

### **Results**

Except for the results from the e-familiarisation sessions the results in the present study are not based on genuine data, and therefore reflects a possible outcome.

### **Participants**

Data sets from 31 participants were included in the wall squat task and 32 were included in the hand grip task. Furthermore, data sets from 16 participants were included in the e-familiarisation.

### **Performance**

#### *Wall squat*

The results from the wall squat performance measured in TTE (Table 1) show a significant main effect of sessions: No-Pain, Throughout-Pain and AMS-Pain ( $F_{1,4,42,1} = 29.75, P < 0.01$ ). Post-hoc testing shows a significant increase in wall squat performance in AMS-Pain compared to No-Pain ( $P < 0.01$ ) and Throughout-Pain ( $P < 0.01$ ) (Figure 5A). However, no significant difference is found between No-Pain and Throughout-Pain ( $P > 0.99$ ).

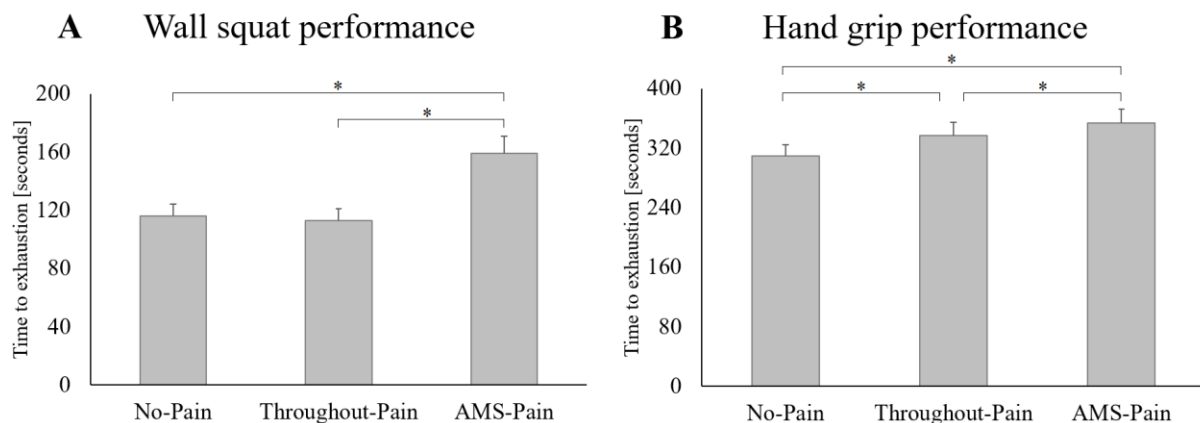
## Hand grip

The results from the hand grip performance measured in TTE (Table 1) show a significant main effect of sessions: No-Pain, Throughout-Pain and AMS-Pain, ( $F_{1.6,48.5}= 18.64, P<0.01$ ). Post-hoc testing shows a significant increase in hand grip performance in Throughout-Pain ( $P<0.01$ ) and AMS-Pain ( $P<0.01$ ) compared to No-Pain. However, additional gains in performance is found in AMS-Pain compared to Throughout-Pain ( $P=0.01$ ) (Figure 5B).

**Table 1 - Performance measured in time to exhaustion**

	No-Pain	Throughout-Pain	AMS-Pain
Wall squat	116.26 ± 44.47	112.84 ± 46.93	159.13 ± 64.24
Hand grip	309.09 ± 88.73	336.50 ± 102.46	353.88 ± 105.70

**Table 1** - Performance measured in time to exhaustion for the two tasks; wall squat ( $n=31$ ) and hand grip performance during 25-30 % maximal voluntary contraction ( $n=32$ ), in the three sessions: No induced noxious electrical stimuli (No-Pain), intermittent noxious electrical stimuli delivered throughout the task (Throughout-Pain), intermittent noxious electrical stimuli initiated at the occurrence of acute muscle soreness (AMS-Pain). The values are presented in mean±standard deviation [seconds].



**Figure 5 - Performance measured in time to exhaustion (TTE).** A) Wall squat performance ( $n=31$ ) and B) hand grip performance during 25-30 % maximal voluntary contraction ( $n=32$ ) in three sessions: no induced noxious electrical stimuli (No-Pain), intermittent noxious electrical stimuli delivered throughout the task (Throughout-Pain), intermittent noxious electrical stimuli initiated at the occurrence of acute muscle soreness (AMS-Pain).

\* represents a significant difference ( $P\leq 0.05$ ) between sessions. Error bars represent standard error of mean.

## Heart rate

### Wall squat

No significant main effect ( $\chi^2(2)=0.17, P=0.92$ ) is found in HR-resting between the three sessions: No-Pain, Throughout-Pain and AMS-Pain. However, the results show significant main effects of sessions in HR in three time points: HR-beforeAMS ( $\chi^2(2)=7.59, P=0.02$ ), HR-duringAMS ( $\chi^2(2)=6.28, P=0.04$ ),

and HR-TTE ( $\chi^2(2)=8.46$ ,  $P=0.02$ ) (Table 2). Post-hoc testing reveals a significant higher HR in Throughout-Pain compared to No-Pain in the three time points (Figure 6A).

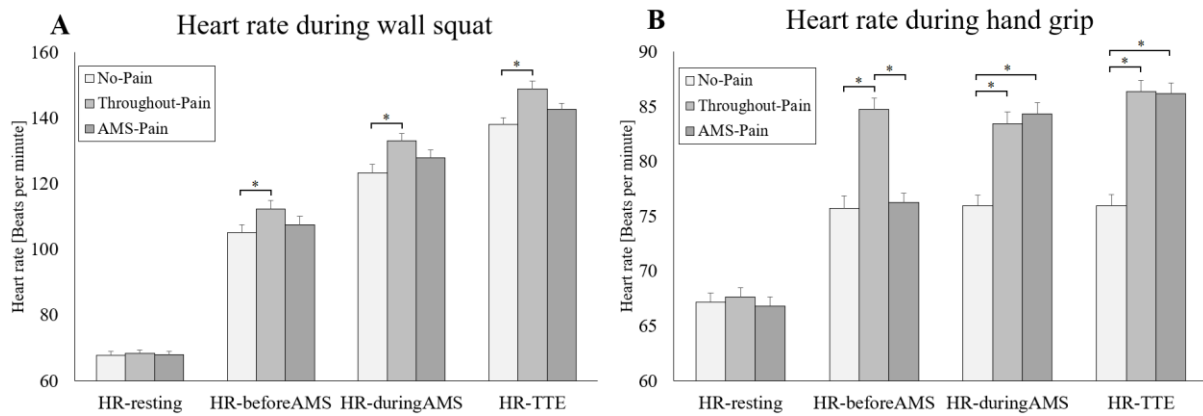
### Hand grip

No significant main effect ( $\chi^2(2)=0.62$ ,  $P=0.73$ ) is found in HR-resting between the three sessions: No-Pain, Throughout-Pain and AMS-Pain. However, the results show significant main effects of sessions in HR in three time points: HR-beforeAMS ( $\chi^2(2)=29.97$ ,  $P<0.01$ ), HR-duringAMS ( $\chi^2(2)=25.51$ ,  $P<0.01$ ), and HR-TTE ( $\chi^2(2)=37.60$ ,  $P<0.01$ ) (Table 2). Post-hoc testing shows a significant increase in HR in Throughout-Pain compared to No-Pain and AMS-Pain at HR-beforeAMS (Figure 6B). Furthermore, a significant increase in HR is found in Throughout-Pain and AMS-Pain compared to No-Pain in the time points: HR-duringAMS and HR-TTE (Figure 6B).

**Table 2 - Relationship between heart rates across sessions.**

<b>Wall squat</b>	HR-resting	HR-beforeAMS	HR-duringAMS	HR-TTE
Main effects	0.92	0.02 *	0.04 *	0.02 *
<i>Post-hoc testing</i>				
No-Pain and Throughout-Pain	-	0.02 *	0.85	0.58
No-Pain and AMS-Pain	-	0.81	0.04 *	0.01 *
Throughout-Pain and AMS-Pain	-	0.31	0.46	0.33
<b>Hand grip</b>	HR-resting	HR-beforeAMS	HR-duringAMS	HR-TTE
Main effects	0.73	<0.01 *	<0.01 *	<0.01 *
<i>Post-hoc testing</i>				
No-Pain and Throughout-Pain	-	<0.01 *	<0.01 *	<0.01 *
No-Pain and AMS-Pain	-	>0.99	<0.01 *	<0.01 *
Throughout-Pain and AMS-Pain	-	<0.01 *	>0.99	>0.99

**Table 2 - Relationship between heart rates across sessions expressed in P-values for main effects and pairwise comparisons between sessions: No induced noxious electrical stimuli (No-Pain), intermittent noxious electrical stimuli delivered throughout the task (Throughout-Pain) and intermittent noxious electrical stimuli initiated at the occurrence of acute muscle soreness (AMS-Pain). The tests were conducted for both the wall squat and hand grip task for each of the four time points: When the participants were at rest (HR-resting), mean HR before the participants felt AMS (HR-beforeAMS), mean HR after the participants felt AMS (HR-duringAMS) and HR when the participants reach time to exhaustion (HR-TTE). \* represents a significant difference ( $P\leq 0.05$ ) between sessions.**



**Figure 6 - Heart rate (HR) during the two tasks.** A) HR during the wall squat task ( $n=31$ ) and B) HR during the hand grip task at 25-30 % maximal voluntary contraction ( $n=32$ ). The figure illustrates mean HR values for the participants in four time points; when the participants were at rest (HR-resting), mean HR before the participants felt AMS (HR-beforeAMS), mean HR after the participants felt AMS (HR-duringAMS) and HR when the participants reach TTE (HR-TTE), in the three sessions: No induced noxious electrical stimuli (No-Pain), intermittent noxious electrical stimuli delivered throughout the task (Throughout-Pain), intermittent noxious electrical stimuli initiated at the occurrence of acute muscle soreness (AMS-Pain). \* represents a significant difference ( $P \leq 0.05$ ) between sessions for each time point. Error bars represent standard error of mean.

### Occurrence of acute muscle soreness

A significant delay for AMS occurrence is found in the wall squat task Throughout-Pain ( $P < 0.01$ ) compared to No-Pain. However, no significant difference for AMS occurrence is found between Throughout-Pain and No-Pain in the hand grip task ( $P = 0.38$ ).

### E-familiarisation

The results for the three e-familiarisation sessions show no significant main effect ( $F_{2,30} = 2.96$ ,  $P = 0.07$ ) in performance measured in TTE. However, a tendency toward an increase in performance concurrently with sessions, as the results show a mean  $\pm$  SD of  $118.81 \pm 46.08$  seconds for the first session,  $123.38 \pm 11.97$  seconds for the second session and  $130.94 \pm 12.48$  seconds for the third session.

### Discussion

The aim of the present study was to investigate the influence of two noxious ES protocols; Throughout-Pain and AMS-Pain in isometric strength-endurance performance in a wall squat and hand grip task, where performance is measured in TTE. It was hypothesised that both ES protocols would improve performance in both tasks compared to no ES, where a greater improvement in performance would be observed in AMS-Pain. The main finding in the present study is that AMS-Pain has the greatest improvement in isometric strength-endurance performance in both the wall squat and hand grip task compared to No-Pain and Throughout-Pain. Furthermore, an increase in performance is found in the

hand grip task in Throughout-Pain compared to No-Pain. These results show that different ES protocols can influence a specific task differently, and that a specific ES protocol can influence tasks differently, indicating the influence of noxious ES may be both protocol and task dependent. Previous studies using ES to improve performance in sport contexts, applied different protocols for the delivering of noxious electrical stimuli. Girolid et al. (2012) investigated the influence of either noxious ES or strength training on swimming performance. The electrical stimuli were delivered one hour prior to performing three times a week for four weeks. Their results show an increase in swimming velocity and peak torque for both the strength training and ES group, and an increased isometric and eccentric peak torque in the ES group compared to the strength training group (Girolid et al., 2012). On the contrary, a study by Venable et al. (1991) found no improvement in vertical jump performance when using noxious ES in combination with strength training three times a week for five weeks compared to a strength training group. Another study used noxious ES to investigate performance in ice hockey, where the electrical stimuli were delivered three times a week for three weeks prior to performing (Brocherie et al., 2005). The results show an increase in skating sprint performance and isokinetic strength (Brocherie et al., 2005). These studies' results are in compliance with the findings in the present study, where different results are found dependent on the protocol and task. However, the previous studies (Brocherie et al., 2005; Girolid et al., 2012) used noxious ES prior to performing and found an improvement in performance after several sessions, whilst the present study applied noxious ES during the tasks and found an improvement in one single session. To the best of our knowledge, this is the first study to explore if noxious electrical stimuli delivered intermittent during a task can influence isometric strength-endurance performance. Furthermore, this is the first study to deliver noxious electrical stimuli after AMS occurrence. The study design in the present study is therefore novel.

In the present study genuine data were obtained by three e-familiarisation sessions, as performance often improves rapidly initially in training (Mazur & Hastie, 1978). However, this was not observed in the present study as the results show no significant difference in performance between the three sessions, yet a tendency towards a small improvement in performance is observed from the first to the last session in the e-familiarisation. The improvements in wall squat performance in the present study may therefore be attributed to the ES.

In the Throughout-Pain and AMS-Pain sessions, two different types of pain were present during the tasks: The pain caused by AMS and the pain induced by ES. AMS can be characterised as a deep muscle pain and may trigger different responses in the nervous system than the pain caused by ES. AMS occurs due to an inadequate blood flow and oxygen delivery to the working muscles, resulting in an accumulation of muscle metabolites (Abraham, 1979; Shephard, 2000). This accumulation may activate the afferent A $\delta$  and C fibres (Bigland-Ritchie et al., 1992), which influences the occurrence of central fatigue (Laurin et al., 2015) and thus limits motor performance (Shephard, 2000). However, the afferent A $\delta$  and C fibres are also activated by ES (Inui et al., 2002). The pain induced by ES is characterised as a cutaneous pain (Riley et al., 1998), and can lead to increased blood flow (Keay & Bandler, 2002),

which may improve motor performance (Shephard, 2000). The influence of the afferent A $\delta$  and C fibres may therefore differ depending on the type of pain. In the present study the greatest increase in performance is observed in AMS-Pain. This indicates that noxious electrical stimuli initiated at AMS occurrence may create favourable physiological advantages for motor performance, and possibly oppose the physiological influences of AMS, as ES may provide adequate blood flow to the working muscles and thus diminish AMS.

Given that AMS occurs due to an accumulation of muscle metabolites (Abraham, 1979), an increase in HR caused by ES may delay AMS occurrence and thus improve motor performance. Noxious ES activates nociceptors and the SNS, resulting in increased HR (Milosevic, 2015; Watanabe et al., 2014), blood flow (Keay & Bandler, 2002), and oxygen delivery to the working muscles, accelerating the removal of muscle metabolites (Shephard, 2000). The ES may therefore contribute to a delay in AMS occurrence, and thus increase performance in the session where electrical stimuli were delivered throughout the task in both the wall squat and hand grip task. In the wall squat task, a delay in AMS occurrence is found in Throughout-Pain concurrently with an increase in HR, yet no improvement in performance is observed. However, an increase in performance is found in the hand grip task concurrently with an increase in HR in Throughout-Pain, yet no delay in AMS occurrence. An increase in HR is observed before AMS occurrence in Throughout-Pain compared to No-Pain in both tasks. Given that an increased HR facilitates blood flow, oxygen delivery and removal of muscle metabolites in the working muscles, a delay in AMS was therefore expected to be observed in both tasks. The credibility of the mock data may therefore be debatable. Since AMS-Pain has a greater increase in performance compared to Throughout-Pain in both the wall squat and hand grip task, a change in HR and AMS occurrence may not be predictors for increased motor performance, and other parameters may therefore influence performance.

Pain often attracts attention (Van Damme et al., 2010), and the participants may therefore have directed their attention to the pain caused by AMS, which may lead to reduced motivation to persist performing and thus facilitate the occurrence of central fatigue (Davis & Bailey, 1997). The participants in the present study were told to perform until TTE and were presumably fully motivated while performing the wall squat and hand grip tasks. However, central fatigue will eventually occur despite the participants being fully motivated (Davis & Bailey, 1997). The pain caused by AMS may further have contributed to central fatigue, as the afferent A $\delta$  and C fibres were activated (Bigland-Ritchie et al., 1992), resulting in a withdrawal from the wall squat or hand grip task. In order to delay the occurrence of central fatigue in the tasks, the ES may divert attention from the pain caused by AMS (Ingham et al., 2011; Passmore et al., 2014), towards the pain induced by the ES. However, attention constantly shifts between sensory events and is mostly directed towards new and unknown events (Van Damme et al., 2010). In AMS-Pain, noxious electrical stimuli were initiated immediately after the participants reported the sensation of AMS, and the two different types of pain therefore arose shortly after one another. As a consequence, the participants' attention may have shifted between the pain

caused by AMS and the ES. Given that the participants in the present study fulfilled the World Health Organization's recommended levels of physical activity, the pain caused by AMS may not be perceived as unknown compared to the pain induced by the ES. On the contrary, the pain induced by ES may be perceived as relatively novel and more attention may therefore have been given to the ES. As the results in the present study show the greatest increase in performance in AMS-Pain compared to Throughout-Pain and No-Pain, the ES may successfully have diverted attention from the AMS to the ES in this protocol, and thus improved isometric strength-endurance performance.

## **Conclusion**

The results from the wall squat task show an improvement in isometric strength-endurance performance in AMS-Pain compared to No-Pain and Throughout-Pain, yet an improvement is not found in Throughout-Pain compared to No-Pain. The results from the hand grip task show an improvement in isometric strength-endurance performance in both pain protocols, however a greater improvement in AMS-Pain is observed. These results indicate that initiating electrical stimuli at AMS occurrence has a greater improvement in isometric strength-endurance performance compared to no electrical stimuli or stimuli delivered throughout the task. This improvement may be due to the physiological advantages caused by noxious ES, as it possibly opposes the physiological influences of AMS. Furthermore, ES may have successfully diverted attention from the AMS arising during exercise towards the noxious ES.

## **Perspectives**

It is assumed that the mock data in the present study reflect a probabilistic outcome and the perspectives are therefore based on this assumption. As the present study found that noxious ES initiated at AMS occurrence improves isometric strength-endurance performance, athletes can benefit from this knowledge by implementing ES during training and competition to achieve improved performance. To apply this knowledge in sport contexts a broader research on how ES influences various performances is needed, in order to investigate the optimal ES protocol and the temporary and long-term influences on motor performance. Moreover, considerations should be evaluated to comply with sport ethics and the health of the athlete.

## **Special equipment and extraordinary training protocols to improve performance**

In sport contexts, there is a continuous development in specialised methods and equipment to improve performance. Special swimsuit technology has been linked to improvements in swim performance (Foster et al., 2012), and studies suggest that the choice of footwear can influence running economy, and thus improve endurance performance (Luo et al., 2009; Sinclair et al., 2016; O'Grady & Gracey, 2020). These specially designed equipment may not provide any discomfort to the athlete contrary to

ES. It may therefore be considered outrageous to induce noxious electrical stimuli to obtain a potentially small improvement in performance. However, precooling, acclimatisation and altitude training are already used in sport to improve endurance performance (Wegmann et al., 2012; Marsh & Sleivert, 1999; Wolski et al., 1996; Roels et al., 2007), and may also be considered painful or uncomfortable (Flouris & Schlader, 2015; Craig, 2013; Wolski et al., 1996). Precooling is primarily used prior to exercising in hot environments and can be conducted in various ways such as water baths, cooling vests and cooling rooms (Wegmann et al., 2012; Marsh & Sleivert, 1999). Depending on the method and severity of the temperature, precooling can result in thermal discomfort (Flouris & Schlader, 2015), shivering (Wissler, 2018), or thermal pain, as skin temperatures below 24 degrees Celsius can activate nociceptors (Craig, 2013). Acclimatisation is mostly used to acclimate to exercising in hot environments (Lorenzo et al., 2010; Wendt et al., 2007), which often takes seven to 14 days of training in a hot environment, and may have a temporary influence on performance (Wendt et al., 2007). Exercise in hot environments can result in thermal discomfort or even hyperthermia (Flouris & Schlader, 2015). Furthermore, altitude training is widely used as it provides long-term improvements on physiological factors critical for endurance motor performance (Savulescu et al., 2004; Kutt, 2005). Altitude training takes place at high altitudes with lower oxygen density than at sea level resulting in reduced oxygen to the working muscles and increased breathing effort (Wolski et al., 1996). Since these uncomfortable methods are already used in sport contexts to improve endurance performance, noxious ES may not be characterised as outrageous to athletes and coaches, and the implementation of ES to improve performance will presumably be well received. Studies investigating the influence of electrical stimuli delivered prior to performance showed improvements in swim and ice-skating performance (Girolid et al., 2012; Brocherie et al., 2005), which indicates that ES has a temporary influence in performance. The present study shows that ES can facilitate an acute improvement in isometric strength-endurance performance when inducing noxious ES during tasks. However, the long-term influences of ES are still unknown.

### **Ethics and doping**

Before using a method to improve performance for competition purposes, considerations regarding whether the method would be considered as doping should be taken into account, and it is therefore important to abide by the World Anti-Doping Agency's (WADA) rules. A substance or method will be considered doping if it fulfils two of the following three criteria: 1) Proof of improving or potential to improve sport performance, 2) evidence of an actual or potential health risk to the athlete, 3) violation of the spirit of sport (World Anti-Doping Agency, n.d.). The first two criteria have a scientific and medical basis, which can determine if the criteria are met (Mazzoni et al., 2011). The third criterion regarding the spirit of sports is however based on societal and ethical perspectives (Mazzoni et al., 2011), which is described in the Anti-Doping Code, referring to intrinsic values in sport and celebrates the human body, mind and spirit (World Anti-Doping Agency, 2019). Ethics, fair play, health, honesty,

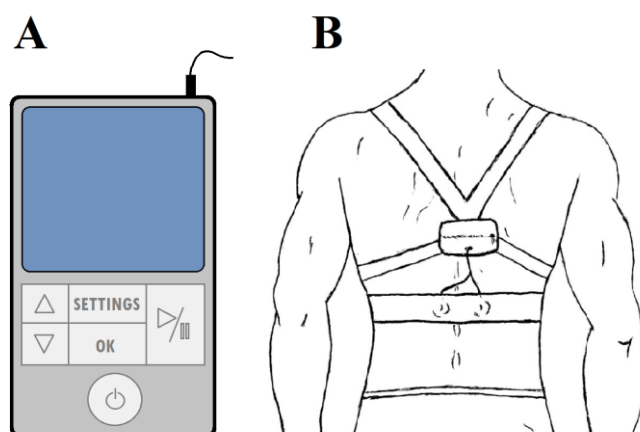


teamwork, respect, solidarity, dedication and excellence in performance reflect some of the values in sport (World Anti-Doping Agency, 2019).

It is established by the present and previous studies (Girolid et al., 2012; Brocherie et al., 2005) that ES has the potential to improve performance, and therefore meets the first of WADA's criteria. ES is described as a non-invasive method (Inui et al., 2002). However, if not used correctly electrical stimuli can cause nerve damage and burns to the skin, or even cardiac arrest (Ferris, 2005; Krasteva & Papazov, 2002). When using ES, direct current with a low amplitude (Ferris, 2005), and low frequency (McCreery et al., 1995) is safest, and does not cause tissue damage. However, nerve damage may occur from a persistent use of ES over long time periods (Yan et al., 2014). To optimise the ES protocol and ensure the second of WADA's criteria is not met, further research is needed in order to investigate, which parameters should be adjusted to produce the greatest improvement in performance without health risks to the athlete. Furthermore, the use of ES must not violate the spirit of sport. To comply with the spirit of sport, transparency is crucial in further research and development of a device delivering the electrical stimuli. Furthermore, the device must be available to all athletes.

### **Design of noxious electrical stimulation device for sport contexts**

The development of an ES device for athletes, can be inspired by already available devices. The inspiration can originate from portable devices for Transcutaneous Electrical Nerve Stimulation, which is a non-painful ES method often used to treat neuropathic, nociceptive and musculoskeletal pain (Jones & Johnson 2009). The device must be simple to use with few adjustable settings (Figure 7A). As mentioned, further research is needed in order to establish how ES can improve motor performance without any health risks. In compliance with previous studies (Girolid et al., 2012; Brocherie et al., 2005; Venable et al. 1991), the present study shows that improvements in performance caused by noxious electrical stimuli are both protocol and task dependent. ES parameters such as waveform, pulse width, pulse frequency, intensity and predictability between stimuli can be adjusted (Doucet et al., 2012). The device can therefore have different settings, where parameters are predetermined dependent on which motor performance the athlete needs improving. Furthermore, the device must be portable, and with the required battery capacity to function even at prolonged training sessions. To ensure that the device (i.e. electrodes and stimulator) does not fall off during exercise, the device must be thoroughly attached to the athlete's body. Inspiration can be found from belt electrodes that are secured around the limb (Miyamoto et al., 2016), and the stimulator can be carried in a body strap system for carrying electronic devices (Elliot, 2002) (Figure 7B). The development of an ES device to improve motor performance still have multiple steps towards being released to the market, however, this study creates the foundation for further research.



**Figure 7 - Illustrations of a possible design for using electrical stimulation in sport contexts.** A) Illustration of a possible design for the electrical stimulator. B) Illustration of a possible method to ensure that the device does not fall off during exercise using a body strap system and a belt containing electrodes.

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### **Conflict of interest**

The authors declare no conflict of interest.

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