Title:

Investigating pain perception during focused hypnotic analgesia: local and remote effects

Abstract:

Hypnosis is increasingly used in clinical contexts to improve pain management and is supported by experimental research, showing reduced pain perception to controlled nociceptive stimuli. This study investigated spatial selectivity of focused hypnotic analgesia (FHA), a technique used to reduce pain in one restricted body part. Series of brief contact heat stimuli were applied randomly to the right and left arm in 40 healthy participants, before, during and after suggestion of FHA targeting one arm. Pain intensity and unpleasantness were assessed after each stimulus using numerical ratings scales. Results showed a significant decrease in pain intensity and unpleasantness for the protected arm during FHA as compared to before and after, whereas no modulation was evidenced for the unprotected arm. Ratings were significantly different between the two arms only during FHA. These results were observed regardless of the level of hypnotizability. This confirms that FHA can selectively modulate pain perception, both its sensory-discriminative and emotional-cognitive components, and restrict its effects on a targeted area without affecting perception on other body parts.

Keywords: pain; nociception; hypnosis; analgesia; focused hypnotic analgesia.

1. Introduction

Hypnoanalgesia, the reduction of pain perception using hypnotic suggestions, has been increasingly studied over the past few decades, and its effectiveness is well established in both experimental and clinical settings (Kendrick et al., 2016; Landry et al., 2017; Merz et al., 2022; Provençal et al., 2018; Thompson et al., 2019). It is used as a treatment for various chronic pain conditions (Del Casale et al., 2015; Langlois et al., 2022; Sine et al., 2022) and for acute pain caused by medical procedures (Tefikow et al., 2013). In the context of surgery, it helps to reduce pain and anxiety, improve post-surgical recovery and patient satisfaction, and reduce the need for anaesthetic and sedative substances as compared to conventional stress management strategies and to general anaesthesia (Tefikow et al., 2013; Thompson et al., 2019; Vanhaudenhuyse et al., 2020).

Among various hypnoanalgesia suggestion procedures, focused hypnoanalgesia (FHA) has attracted significant interest. FHA involves selectively modulating pain by inducing analgesia in a specific area of the body and is commonly used for wound care (Denman, 2024), injections, blood intake and surgical procedures (Kuttner, 2012). Compared to other hypnotic analgesia suggestions (i.e. deep relaxation, neutral hypnosis, dissociative imagery), FHA has been identified as the most effective in reducing both pain intensity and distress (De Pascalis et al., 1999, 2001; Sharav & Tal, 2004; Zachariae & Bjerring, 1994). This suggests that different pain modulation strategies may be involved, depending on the type of hypnotic suggestion. Supporting this idea, Sharav & Tal (2004) found that the mechanisms underlying pain modulation using hypnotic analgesia varied depending on the specific suggestion employed. Their study revealed that when hypnotic analgesia was induced through a general relaxation suggestion, pain perception decreased uniformly across all levels of painful stimulation. In

contrast, during FHA, the reduction in pain perception followed an exponential pattern, with greater pain relief occurring as stimulation intensity increased. This finding suggests that FHA may engage distinct neural and cognitive mechanisms compared to relaxation-based suggestions, further reinforcing the notion that different hypnotic analgesia suggestions operate through different processes to achieve pain relief (Sharav & Tal, 2004).

The underlying mechanisms of FHA remain nevertheless poorly understood. Several studies have shown that it can modulate both the perception of pain and cortical responses to painful stimuli compared to a control condition in which no analgesic suggestion was applied (Casiglia et al., 2020; De Pascalis et al., 2008; Fardo et al., 2015; Friederich et al., 2001). However, these studies did not compare responses to stimulation of the limb on which FHA is induced to those of another body part, making it impossible to determine whether the analgesic effects of FHA are selectively restricted to the protected limb or act in an unspecific way on the whole body. To our knowledge, only four studies have used another body part (i.e. one that is outside the region targeted by the suggestion) as a control to investigate whether FHA is indeed selectively restricted to the protected limb (Benhaiem et al., 2001; Facco et al., 2011; Paqueron et al., 2019; Sharav & Tal, 2006). For instance, it has been shown that the heat pain threshold was higher for stimuli applied to the body area protected by FHA than to the unprotected area (control limb), a difference that was not observed before nor after FHA (Benhaiem et al., 2001; Facco et al., 2011). Using a similar paradigm, Sharav & Tal (2006) found that stimuli applied to the FHA-protected site were perceived as less painful than those applied to a control site during the suggestion, while no such difference was observed between the FHA-protected and control limbs before and after the suggestion (Sharav & Tal, 2006). More recently, a study using infrared thermography showed that in addition to a reduction of pain perception, increases or decreases in local skin temperature were observed

at the FHA-protected site compared to the control site (Paqueron et al., 2019), This suggests that FHA may involve top-down autonomic regulation resulting in local vasomotor changes that vary across individuals.

Together, these studies show the ability of hypnoanalgesia to focus its effect on a specific part of the body. However, these studies attempted to characterize hypnoanalgesia as a selective process by applying stimuli to a single area at a time (local or remote site of FHA) and testing the different areas in separate blocks. By doing so, they do not rule out the contribution of other phenomena such as anticipation or expectation to the observed modulations, since a single body area is stimulated throughout a whole block of trials. It has been repeatedly shown that subjectively expecting a stimulus to be less or more painful can modify pain perception even when the physical intensity of the stimulus remains unchanged (e.g. Atlas & Wager, 2012; Jepma et al., 2018). Alternatively, presenting the stimuli of the different experimental conditions randomly within the same stimulus block reduces the participant's ability to predict which condition the forthcoming stimulus will belong to. For example, in a study investigating the effect of spatial attention on cortical responses to nociceptive stimuli, Legrain et al. (2002) applied stimuli to both hands in a randomized order within the same stimulation blocks and instructed participants to focus their attention on one hand while ignoring stimuli applied to the other hand. They showed that event-related brain potentials (ERPs) evoked by stimuli on the attended hand were larger in magnitude than ERPs evoked by stimuli on the opposite hand during the same blocks. Additionally, the ERPs for the attended hand were larger compared to those for the same hand when it was unattended in other blocks. This allowed them to conclude that attention was selectively modulated (Legrain et al., 2002).

Hence, building on this latter experimental procedure, the aim of the present experiment was to investigate the selective effect of FHA on a restricted body area by comparing the pain levels induced by stimuli applied to two different limbs. To achieve this, painful heat stimuli were randomly applied to one of the two forearms at a time during the same stimulation blocks at three different timepoints: before, during and after FHA was suggested on one arm using the protective glove procedure. We hypothesized that, as compared to before and after conditions for which no difference is expected, during the suggestion of FHA stimuli applied to the protected arm would elicit lower pain ratings than those applied to the unprotected arm. Additionally, we expected the decrease in pain during the suggestion, relative to before it, to be significantly greater for the protected arm than for the unprotected one.

2. Material and Methods

2.1. Participants

Forty healthy volunteers (29 women, 11 men) aged between 18 and 36 years old (M = 24.6, SD = 4.2) participated in the experiment. Participants were recruited through advertisements posted in recruitment groups on the institution's social media. Exclusion criteria were history of chronic pain, severe neurological or psychiatric pathology, current or recent tissue damage or dermatological disease of the hands or forearms, trauma to the upper limbs within the last six months, regular use of psychotropic drugs, intake of step 1 analgesic (e.g. paracetamol and non-steroidal anti-inflammatory drugs) within the 12 hours before the experiment and excessive caffeine consumption (more than 3 cups of coffee per day). A written consent form was signed by all participants, and the study was approved by the local ethical committee (N°B403201214265) and followed the Declaration of Helsinki.

2.2. Stimuli and apparatus

Thermal nociceptive stimuli consisted on contact heat stimuli delivered by two Peltier thermodes (Thermal Cutaneous Stimulator II (TCS II), QST.Lab, Strasbourg, France) and were applied onto the skin of both volar forearms of participants. The surface of each probe is composed of a 30-mm diameter disc divided into five zones, each consisting of three 3.2*2.4 mm^2 thermodes, leading to a total stimulus surface of approximately 1.2cm^2. Although each zone can be independently activated, all of them were simultaneously and synchronously operating during this experiment. Baseline temperature of each thermode was set at 32°C and heating ramp of the device was of 300°C/second, allowing to generate brief and sharp-onset thermal stimuli. Target temperature, that is the temperature used for the experiment, was set at a level ranging from 60°C to 70°C depending on the sensitivity of participants (see threshold measurement procedure below). Each stimulus lasted for 200ms comprising the heating of the thermodes and the plateau at the target temperature. Return to the baseline temperature was achieved by active cooling at a speed of 300°C/s. Such stimulation profile allows the generation of responses compatible with the specific activation of Aδ nociceptive fibres (e.g. Lejeune et al., 2023). In order to avoid habituation or sensitization, the probes were displaced after each stimulus across 6 different predefined zones, and a delay of 5 to 10 seconds was observed between successive stimulations. To this aim, the length of the forearm was measured from the flexion fold of the wrist to the fold of the elbow and then divided into 4 zones. The width of the forearm was then measured at its largest and narrowest parts in order to draw a mark at the middle of each measure and then equally divide the 4 zones into 8. The two first zones starting from the wrist were not stimulated as the presence of ligaments does not allow the stimulation probe to be fully in contact with the skin.

2.3. Procedures

Participants were seated in a chair equipped with a support for the head, neck and shoulders, placed in the centre of the room and faced an occulted window. The main investigator (A.V.C.) trained in hypnosis, managed the entire procedure and was responsible for delivering the hypnotic analgesia suggestion. Two other experimenters (C.B. and M.D.) oversaw the application of stimuli and data recording.

Briefing and instructions were provided orally by the principal investigator, and participants were asked to complete the written consent form. The experiment began by determining the target temperature of the stimuli for each participant, which was done by measuring the heat pain threshold using the method of limits (Tiberghien, 1984). Stimuli were applied to the volar forearm starting at 58°C and increasing in 2°C increment until the highest bearable temperature was reached, with a maximum of 70°C for technical and safety purposes. After each stimulus, participants were asked to rate the perceived pain intensity on a numerical rating scale (NRS) ranging from 0 to 100 (0= no sensation; 50= pain threshold; 100= the most painful stimulus imaginable) and perceived unpleasantness, also ranging from 0 to 100 (0= not unpleasant; 100= the most unpleasant stimulus imaginable). The procedure was completed separately for both arms. Stimulus temperatures were determined to elicit equal pain ratings on both arms (with less than 5% of difference between the two ratings) and to be as close as possible to the highest bearable stimulus temperature.

The experimental session per se was divided into three experimental blocks, each of them lasting on average five minutes. During each block, 20 nociceptive stimuli were delivered, with 10 applied to each forearm in a random order. After each stimulus, participants were asked to rate pain intensity and unpleasantness associated with the stimulus according to the two different scales mentioned above. Once a block was completed, the investigator

asked four questions regarding items characterizing the hypnotic experience: absorption, dissociation, time perception and automaticity (Rainville et al., 2019; Vanhaudenhuyse et al., 2019). To control for any bias related to the experimenter, the person applying stimuli to one forearm (i.e. left or right) was counterbalanced between the participants. The three blocks were structured as follow:

- In the first block, stimuli were delivered before FHA, with no specific instruction given to the participant except to look straight ahead without shifting their gaze to the left or right, in order to avoid inducing a visuospatial bias (*before* condition).
- In the second block, stimuli were delivered while FHA was applied to one of the two arms using the procedure of the protective glove (see details below). To match the other conditions, participants could not close their eyes and were instructed to look straight ahead (*during* condition).
- In the third block, stimuli were applied after the protective glove was removed (see details below) following the experimenter's instructions. As in the first two blocks, participants were instructed to look straight ahead while nociceptive stimuli were delivered (*after* condition).

After the 3 blocks, participants completed the short version of the Edinburgh Handedness Inventory (EHI) (Oldfield, 1971) to assess their handedness. The experimenter then administrated the Elkins Hypnotizability Scale (EHS) (Elkins, Barabasz, et al., 2015; Elkins, Johnson, et al., 2015; Kendrick et al., 2016) to determine the participants' hypnotizability. Finally, a debriefing of the experiment was conducted, followed by the compensation and the completion of the receipt (see Figure 1).

[Figure 1]

Focused hypnotic analgesia procedure

During FHA, the two experimenters responsible for applying the stimuli left the room to remain blind regarding which arm was chosen for protection and to avoid any stimulus bias. They returned only after the procedure was completed. FHA was induced using the *protective glove* technique, based on the guidelines of Virot & Bernard (Virot & Bernard, 2018). This method does not require a formal hypnotic induction but rather relies on focusing the participant's attention on one body part, which is suggested to become analgesic, and dissociating it from the rest of the body. In this way, the participant remains responsive and is able to interact with the environment. Originally, the technique involves building a protective glove around the hand, but it was adapted in this experiment to protect the area stimulated by the contact-heat thermodes. Therefore, participants were asked to wear a sleeve or any object that evoked the sense of protection on their forearm.

First, the experimenter asked the participant which forearm they preferred to protect. The choice was left to the participant to avoid inducing any conscious or unconscious resistance to the protection, and the question was formulated to encourage dissociation between the participant and their arm: "*which arm would like to be protected?*". If no preference was expressed, the experimenter selected the arm to ensure that the number of participants protecting the right (n=20) and left (n=20) arms was the same.

Once the protected arm was determined, the experimenter sat next to the participant and began the procedure by applying a slight pinch to the skin of the forearm. This was done to make the participants aware of the pain that could be encountered on the arm, to give a reminder of the sensation it produces and therefore to motivate them to protect themselves by responding to the suggestion. The participant was then invited to mentally recall of an

object that could be used to protect their forearm from pain. No restrictions were given, except that the object had to exist in their home and be familiar to them. Once the object was chosen, the experimenter asked the participant to describe it in detail, including its function, size, colour, material, texture and thickness. After the participant took a deep breath and collected visual and auditory references from the room, the experimenter requested permission to lift their forearm by the wrist and placed it in catalepsy. The participant was then invited to imagine wrapping the protective object around their forearm. No specific instructions were given regarding eye closure, allowing participants to decide what felt most comfortable for them. While the participant was putting on the protection, the experimenter provided suggestions to focus on the materiel and texture on the skin, and to recall the details of its colour.

Once the participant confirmed that the protection was properly settled, the next step was to reinforce it by adding a layer of cotton, similar to what is used to build a cast. The experimenter started by asking what colour the cotton layer was and then invited them wrapping it around the forearm, on top of the previously applied protection. To assist with this process, the experimenter visually mimicked wrapping the band around the participant's forearm while providing suggestions of increased protection and analgesia. Depending on their individual preference, participants could rather be visually guided by the movement made by the experimenter around their arm, or concentrate their gaze somewhere else/close their eyes, and use their own visual imagery. In that latter case, they could only benefit from the sensory cues produced by the wrapping movement made by the experimenter around the participant's arm. After completing two full passes over the forearm, the experimenter stopped the movement and asked the participant whether enough cotton had been added to

create an effective protection against pain. If necessary, additional cotton was mentally added to specific areas identified by the participant.

The last step involved adding a layer of resin over the cotton. The experimenter explained that the resin was initially soft, and gradually dried around the forearm, until it became as hard as concrete. This explanation was reinforced by the sound of knocking on a hard surface such as the wall. The same procedure used for the cotton layer was then completed. Once the resin layer was applied, the experimenter instructed the participant to take a moment to feel the resin drying and hardening, again accompanied by a knock on the wall. It was emphasized that the harder and stiffer the protection became, the more protective and efficient it would be. Once the participant felt that the layer was dry and solid enough, it was asked to keep it in place, as it would be essential for the next step of the experiment. To end the procedure, the experimenter applied the same pinch as before building of the protection. This was done to check the efficiency of the suggestion, and to bring the participant to realize the modulation of perception compared to the initial sensation. In addition, a pinch was administered on the control forearm to compare pain perception between the *protected* and *unprotected* forearms. If no modulation was perceived on the protected forearm, the participant was informed that the time needed for the suggestion to be efficient could vary across individuals, and additional time was given to reinforce the suggestion by themselves relying on the previously delivered suggestions. They were asked to inform the experimenter once their thought they were ready. Finally, the participant was informed that the protection they had created could be reused whenever they need to protect themselves from pain. Therefore, when the experimenter would suggest it, they should remove the protection and store it somewhere in their mind, where they knew they could reuse it if necessary.

After the *during* block was completed, the experimenter instructed the participant to remove the protection and to give a sign once they felt it was taken off and stored. The participant was then asked to rub both forearms with their hands to restore equal sensations between the two arms.

2.4. Measures:

2.4.1. Pain intensity and unpleasantness

Measures of pain intensity and unpleasantness were collected following each stimulus. Ratings of intensity were evaluated on a numerical rating scale ranging from 0 (no sensation) to 100 (worst pain imaginable) with a cut off at 50 representing the transition from a non-painful to a painful sensation. Ratings of unpleasantness were evaluated on a numerical rating scale ranging from 0 (not unpleasant) to 100 (most unpleasant sensation imaginable). For both intensity and unpleasantness assessments respectively, stimulus ratings were averaged for each participant and each of the conditions yielding 6 values resulting from the combination of *time* (i.e. *before*, *during*, *after*) and *arm* (i.e. *protected*, *unprotected*) factors.

2.4.2. Four items of hypnotic experience

After each experimental block, four items measuring aspects of hypnotic experience were assessed. Those items consist of a self-assessed measure of the participant's hypnotizability state. Each item reflects a specific aspect of the hypnotic experience: absorption, dissociation, time perception, and automaticity (Rainville et al., 2019; Vanhaudenhuyse et al., 2019). Evaluation of all four items was collected after each experimental block to monitor the hypnotic state and its fluctuations depending on the experimental conditions. The items were systematically presented in the same order, with participants responding to the following instructions:

- Dissociation: "*Could you estimate on a 0-to-10 scale if you felt a dissociation between your bodily sensations and the actual environment? Zero means you were in the reality, in this room; 10 means that you completely escaped in your subjective experience, totally disconnected from the here-and-now reality*."
- Absorption: "*Could you estimate on a 0- (not at all) to 10- (fully) scale how deeply you felt absorbed and felt your attention as focalized and focused by the experience you have just lived?*"
- Time perception: "*Could you estimate, in terms of minutes, the time that the experimental block lasted?*"
- Automaticity: "*Could you estimate, on a 0-to-10 scale, the level with which you were controlling your actions and thoughts? 0 refers to a state where you were the passive witness of your actions and thoughts, they were coming and going naturally without having the impression that you were at the origin of them. 10 means a feeling of perfect control, where you had the impression of being the engine, the actor of your actions and thoughts.*"

For each participant, three measures of each item were obtained, one for each timepoint (i.e. before, during and after FHA). The measure of time perception is calculated by subtracting the perceived duration from the actual duration of the block.

2.4.3. Hypnotizability

Hypnotizability was measured at the end of the experimental session using the Elkins Hypnotizability Scale (EHS) (Elkins, Barabasz, et al., 2015; Elkins, Johnson, et al., 2015; Kendrick et al., 2016). The assessment of the EHS was carried out by the principal investigator. The scale comprises 6 items aiming at evaluating the level of hypnotizability of a participant. The items

are presented in a specific order, ranging from the most accessible suggestion to the most difficult one. After completion of the items, responsiveness to each item is evaluated depending on visual observation made by the experimenter during hypnosis, in addition to subjective feedback given by the participant after the hypnotic session. The final score ranges from 0 to 12. A score from 0 to 3 refers to low hypnotizability, 4 to 7 a medium hypnotizability, 8 to 11 a high hypnotizability, and 12 a very high hypnotizability. The assessment lasted approximately 30 minutes. No very high hypnotizable subject was encountered. Therefore, participants were assigned to one out three groups using their individual score (i.e. low vs. medium vs. high hypnotizable groups).

2.5. Analyses

Statistical analyses were conducted using JASP 2023 (version 0.17.2.1) and IBM SPSS Statistics (28.0.0.0.). The impact of FHA on pain ratings were tested according to two analyses.

In the first analysis, intensity and unpleasantness ratings were respectively compared using a 3*2*3 ANOVA for repeated measures with *time* (*before*, *during*, *after*) and *arm* (*protected*, *unprotected*) as within-participant factors, and *hypnotizability* (*low*, *medium*, *high*) as a between-participant factor. Sphericity assumption was checked using the Mauchly test, and Greenhouse-Geisser correction of degrees of freedom was applied when necessary. Post-hoc analyses were performed by means of paired-samples t-tests with Holm correction to uncover specific differences.

The second analysis compared changes in perception from one timepoint to another between the two arms. To this aim, delta scores were obtained by calculating the difference for each arm of ratings between *before* and *during*, *during* and *after*, and *before* and *after* respectively. Delta scores were first compared to 0 using one-sample t-tests to test whether

the changes between two timepoints were significant. Next, paired-samples t-test were conducted to test whether those changes were different between the two arms. As the *hypnotisability* group factor never had a significant effect on the previous analyses (see Results section), it was discarded from the latter analyses.

In addition, the four measures of absorption, dissociation, time perception and automaticity were analysed using Friedman tests for repeated measures with *time* (*before*, *during*, *after*) as within-participant factor. Contrast analyses were conducted using Wilcoxon signed-rank tests to highlight differences between levels of significant factors.

For all analyses, normality of the dependent variables was tested using the Shapiro-Wilk test. Effect size was assessed using partial Eta squared for ANOVA and Cohen's d for t-tests. Results were considered as statistically significant when $p < .05$.

3. Results

Based on the participants' scores to the EHS, the sample was composed of 7 low hypnotizable (LH) (EHS score 0-3), 22 medium hypnotizable (MH) (EHS score 4-7) and 11 high hypnotizable (HH) (EHS score 8-11) participants (see Table 1 of the supplementary material for descriptive statistics on the EHS and the 4 items of hypnotic experience). Based on their pain threshold measurements, the target temperature of the stimuli was on average of 66.4°C (SD = 2.8°C, min = 60°C, max = 70°C).

Shapiro-Wilk tests for normality applied to the different variables of pain perception and unpleasantness perception showed no significant effect for any rating scores, except for the unpleasantness rating of the local arm during FHA (p=.037). Therefore, parametric data analysis procedures were used as planned.

3.1. Pain intensity and unpleasantness

Since the group factor *hypnotizability* had no significant main effect and did not interact significantly with any of the other factors, neither for the intensity ratings (all $F \leq .91$, $p \geq .410$) nor for the unpleasantness ratings (all $F \leq .49$, all $p \geq .656$), the analyses are reported without this factor and only with the within factors *time* and *arm* (i.e. ANOVA 3*2).

Results for intensity ratings revealed a significant main effect of the factor time ($F(2,78) = 12.47$, $p < .001$, $\eta^2p = .242$) and a significant interaction between *time* and *arm* ($F(2,78) = 11.93$, $p < .001$, $\eta^2p = .234$). The main effect of *arm* was not significant ($F(1,39) = 1.07$, $p = .307$, $\eta^2p = .027$). Post-hoc analyses performed on the *protected* arm showed that pain intensity ratings were lower *during* as compared to *before* FHA (before: M = 55.09 ± 15.58; during: M = 47.02 ± 19.74; $t(39) = -6.28$, $p_{holm} < .001$, $d = -.452$), and higher *after* FHA as compared to *during* (after: M = 52.19 ±18.93; $t(39) = 4.02$, $p_{holm} = .001$, $d = .290$) (see Figure 2). There was no significant difference between *before* and *after* FHA ($t(39) = 2.26$, $p_{holm} = .154$, $d = .163$). All those comparisons were not significant for the *unprotected* arm (*before* = 54.68 ± 16.79, *during* = 51.45 ± 18.08, *after* = 51.3 ± 17.62; all $|t| \leq 2.64$, all $p_{holm} \geq .094$, all $|d| \leq .190$).

When comparing intensity ratings between the two arms at each timepoint, ratings were significantly smaller for the *protected* arm than for the *unprotected* arm *during* FHA ($t(39) = -3.62$, $p_{holm} = .006$, $d = -.248$), whereas this difference was not significant neither *before* ($t(39) = 0.33$, $p_{holm} = 1.000$, $d = .023$) nor *after* ($t(39) = 0.73$, $p_{holm} = 1.000$, $d = .050$) (see Figure 2).

Figure 2 shows that some participants perceived the stimuli at the timepoint *before* on average as non-painful (n = 13). To assess whether this could have influenced the previously reported results, a complementary analysis was conducted. Specifically, a between-subjects factor with two levels was added to the initial ANOVA (see above): Group 1 included

participants who, on average, rated the stimuli as < 50/100 at timepoint *before*, and Group 2 included those who rated them as > 50/100. The results of this analysis, available in the supplementary material (Table 2), showed that this factor had no significant influence on the previously reported results.

[Figure 2]

Analyses performed on the delta scores for pain intensity ratings changes across timepoints using one-sample t-tests showed that all variables were different from zero (all $t(39) \geq 2.417$, all $p \leq .02$) except for the *after-during* delta scores for the *unprotected* arm ($t(39) = -0.186$, $p = .853$) and the *before-after* delta scores for the *protected* arm ($t(39) = 1.993$, $p = .053$). Results for the comparison of *before-during* showed a significant difference between the arms, suggesting that reduction of intensity rating was significantly more important for the *protected* than for the *unprotected* arm (protected = 8.07 ± 7.86, unprotected = 3.23 ± 7.78, $t(39)= 3.92$, $p < .001$, Cohen's d =.619). The comparison of the *after-during* delta scores was also significant, showing a greater change in pain intensity perception from *during* to *after* FHA for the *protected* than for the *unprotected* arm (protected = 5.17 ± 9.053, unprotected = -0.15 ± 5.286, $t(39) = 4.34$, $p < .001$, Cohen's d = .686). Note that the *after-during* delta scores are opposite for the two arms, meaning that while the perception of intensity increased for the *protected* arm from *during* to *after* FHA, it tended to decrease for the *unprotected* arm (see Figure 3). The differences between *before* and *after* FHA were not significantly different between the two arms (protected = 2.90 ± 9.204, unprotected = 3.39 ± 8.865, $t(39) = -0.424$, $p = .674$, Cohen's d = -0.067).

[Figure 3]

Analyses of unpleasantness ratings showed a significant main effect of *time* ($F(1.68,65.39) = 11.65$, $p < .001$, $\eta^2p = .230$) and a significant interaction between *time* and *arm* ($F(2,78) = 14.01$, $p < .001$, $\eta^2p = .26$), but no significant main effect of *arm* ($F(1,39) = 1.05$, $p = .312$, $\eta^2p = .026$). Post-hoc analyses showed that for the *protected* arm, unpleasantness ratings were lower *during* FHA as compared to *before* (before: M = 40.81 ± 19.76, during: M = 32.54 ± 21.74, $t(39) = -6.08$, $p_{holm} < .001$, $d = -.392$) and compared to *after* (after: M = 38.07 ± 21.49, $t(39) = -4.06$, $p_{holm} = .001$, $d = -.262$) (see Figure 4). No significant difference between *before* and *after* was found for the *protected* arm ($t(39) = 2.02$, $p_{holm} = .277$, $d = .130$). For the *unprotected* arm, no significant comparison was observed (before = 40.591 ± 20.58, during = 36.99 ± 21.60, after = 36.77 ± 21.33; all $t \leq 2.804$, $p \geq .066$).

Comparison between the two arms showed significantly smaller ratings of unpleasantness for the *protected* arm as compared to the *unprotected* one *during* ($t(39) = -3.82$, $p_{holm} = .003$, $d = -.211$), but not *before* ($t(39) = 0.19$, $p_{holm} = 1.00$, $d = .011$) nor *after* FHA ($t(39) = 1.13$, $p_{holm} = 1.00$, $d = .061$).

[Figure 4]

Results of the one-sample t-tests performed on the delta scores for unpleasantness ratings changes revealed that all scores were significantly different from zero (all $t \geq .2.502$, $p \leq .017$) except for the *after-during* delta scores for the unprotected arm ($t(39) = -252$, $p = .802$) and *before-after* delta scores for the *protected* arm ($t(39) = 1.820$, $p = .076$). Results comparing unpleasantness ratings changes between *before* and *during* showed a significant difference between the two arms, suggesting a greater decrease of unpleasantness perception during FHA for the *protected* arm than for the *unprotected* one (protected = 8.37 ± 8.98, unprotected = 3.64 ± 8.83, $t(39) = 3.79$, $p < .001$, Cohen's $d = .599$). A significant *after-during* difference was

also found between the two arms, suggesting different changes of unpleasantness from *during* to *after* FHA between the protected arm and the unprotected one (protected = 5.53 ± 8.45; unprotected = -0.217 ± 5.45, t(39) = 4.809, p < .001, Cohen's d = .760). It should be noted that the *after-during* delta scores show opposite tendencies for the two arms, as the perception of unpleasantness increased for the *protected* arm from *during* to *after* FHA, and decreased for the *unprotected* arm (see figure 5). No significant difference was observed between the arms when comparing *before-after* changes (protected = 2.744 ± 9.54, unprotected = 3.816 ± 9.648, t(39) = -1.077, p = 0.288, Cohen's d =-0.170).

3.2. Four items of hypnotic experience

Analyses on the four items measuring dimensions of the hypnotic experience revealed no significant difference between the difference timepoints for *absorption*, ($\chi^2(2) = 2.9$, p =.235), *time perception* ($\chi^2(2) = 4.13$, p = .127) nor *automaticity* ($\chi^2(2) = 0.46$, p = .796). Nevertheless, a significant difference was found for *dissociation* ($\chi^2(2) = 24.28$, p <.001). Post-hoc analyses showed that dissociation increased *during* FHA (M = 4.66 ± 2.56) as compared to *before* (M = 3.24 ± 2.54; z = 3.96, $p_{holm\text{-}bonf}$ = .003, r = .790) and *after* (M = 3.49 ± 2.34; z = 3.07, $p_{holm\text{-}bonf}$ = .004, r = .643). There was no difference for *dissociation* between timepoints *before* and *after* FHA (z = -.97, $p_{holm\text{-}bonf}$ = .328, r = -.192) (see Figure 6).

To determine whether changes in dissociation between timepoints *before* and *during* were associated with changes in pain intensity and unpleasantness for both the *protected* and *unprotected* arms, correlation tests were conducted on the difference of score between *before* and *during* for each measure (i.e. pain intensity, pain unpleasantness and dissociation). Spearman's rho was chosen as outliers were highlighted and linearity was not encountered for several variables. No significant correlations were found (dissociation & intensity –

protected: ρ (38) = -.002, p = .992, z = -.002; – unprotected: ρ (38) = .058, p = .723, z = .058; dissociation & unpleasantness – protected: ρ (38) = -.064, p = .695, z = -.064; – unprotected: ρ (38) = -.014, p = .931, z = -.014). The same analyses were applied to differences between the *after* and *during* timepoints, again revealing no significant correlations (dissociation & intensity – protected: ρ (38) = -.192, p = .234, z = -.195; – unprotected: ρ (38) = -.064, p = .695, z = -.064; dissociation & unpleasantness – protected: ρ (38) = -.232, p = .150, z = -.236; – unprotected: ρ (38) = -.004, p = .982, z = -.004) (see table 3 of supplementary material).

[Figure 6]

4. Discussion

The aim of the present study was to investigate the ability of focused hypnotic analgesia (FHA) to selectively modulate pain perception, that is, to modulate the perception induced by nociceptive stimuli applied to the limb where the suggestion of hypoalgesia is focused, without affecting the perception induced by the same stimuli applied to another limb. To achieve this, thermonociceptive stimuli were randomly applied to both forearms of each participant *before*, *during* and *after* FHA was administered to one of them using the protective glove technique. Measures of pain intensity and unpleasantness were collected after each stimulus. We had hypothesized that pain intensity and unpleasantness ratings would be lower on the *protected* arm compared to the *unprotected* one specifically *during* the suggestion of FHA, while no such difference was expected *before* or *after* the suggestion. Furthermore, we predicted that the reduction in pain from *before* to *during* the suggestion phase would be significantly greater for the *protected* arm than for the *unprotected* arm. Also, we expected that modulation of pain intensity and unpleasantness would vary according to the level of hypnotizability, with individuals exhibiting higher hypnotizability showing a greater

reduction in pain perception *during* FHA compared to *before* and *after*. Similarly, it was hypothesized that dissociation, automaticity, and absorption would increase *during* FHA, while time perception would decrease.

Results showed significant differences in both pain intensity and unpleasantness between the *protected* and *unprotected* forearms. *During* FHA, stimuli applied to the *protected* arm elicited lower pain intensity and unpleasantness ratings than those applied to the *unprotected* arm, whereas no differences between the arms were observed *before* or *after* the suggestion. In addition, ratings for the *protected* arm were lower *during* FHA compared to both *before* and *after*, while no significant differences were observed between the three timepoints for the *unprotected* arm. Analyses of the delta scores of pain intensity and unpleasantness between timepoints revealed that the decrease of pain *during* relative to *before* the suggestion was greater for the *protected* arm than for the *unprotected* one. Furthermore, the comparison of the *after-during* delta scores was also significant, with a greater change in pain intensity and unpleasantness for the *protected* arm. This finding aligns with the idea that, once the protection is removed, sensation returns to a level close to the initial state.

Overall, the present results demonstrate that FHA suggestion can selectively modulate pain perception within a restricted area of the body. Specifically, only the protected arm showed a decrease in pain intensity and unpleasantness, while no modulation was observed in the unprotected arm. This suggests that the observed changes were due to the hypnotic suggestion itself, rather than to a general reduction in pain perception across the body. These findings are in line with those of Sharav and Tal (2006) who also reported a localized reduction in pain perception to electrical stimuli in the FHA-targeted area, with no effect on the control

limb. However, contrasting evidence is found in the study of Benhaiem et al. (2001), where pain threshold increased not only in the protected area but also, to a lesser extent, in the unprotected site. This indicates that FHA suggestions might exert broader, non-specific effects depending on the type of pain measure—suggesting that pain threshold and pain perception could be modulated through partially distinct mechanisms.

Essentially, the design of the present study offers a methodological advance over previous work. By randomizing the delivery of stimuli between the protected and control sites, we minimized the influence of non-specific cognitive factors such as anticipation or expectation. This design reinforces the interpretation that the modulation of pain perception was indeed selective, and attributable specifically to the spatial focus of the suggestion—something that earlier studies could not clearly establish. Moreover, since pain modulation was observed in both intensity and unpleasantness, these findings, in agreement with previous research (Sharav & Tal, 2006), suggest that hypnosis can selectively influence different aspects of pain processing, including sensory-discriminative and emotional-cognitive components.

Regarding underlying physiological mechanisms, in a study comparing wakefulness vs. FHA during functional magnetic resonance imaging, Casiglia and colleagues (2020) have observed a decreased activity in the primary somatosensory cortex, anterior cingulate cortex and prefrontal cortex during FHA (Casiglia et al., 2020). As FHA seemed to alter the activity of cortical regions involved in the processing of nociceptive afferents, authors suggest that the technique may actually prevent noxious stimuli from reaching the cortical areas where they are processed as painful. However, since the study was designed to investigate the general hypnotic effect rather than the spatial selectivity of the analgesia on a particular body area, it

does not allow us to determine whether the observed modulation was due to hypnosis itself or to the specific mechanisms of FHA. It is therefore currently difficult to understand the neural mechanisms by which hypnosis selectively modulates the perception of stimuli applied to a restricted part of the body. However, some suggestions can be made based on the analogy to studies conducted on selective attention in somatosensory modalities. Most of these studies have been conducted using event-related evoked potentials (ERPs) and show that selectively paying attention to a certain body part modulates the amplitude of ERP components that are supposed to reflect the activity of the primary and mostly the secondary somatosensory regions (e.g. Desmedt & Robertson, 1977; Forster et al., 2016; Forster & Eimer, 2005; Gherri et al., 2023; Michie, 1984; Michie et al., 1987; Mima et al., 1998; see Sambo & Forster, 2011 for a review). Since these areas represent some somatotopy of the body, this suggests that attention could selectively modulate the response of neurons receiving inputs from the body region on which attention is focused (Sinclair, 2000). However, most of these studies have been conducted using non-painful innocuous stimuli and therefore cortical responses evoked by activation of the lemniscal system. Very few have been carried out using stimuli that specifically activate thermonociceptive fibres. For example, Legrain et al. (2002) applied radiant heat stimuli to the back of their participants' hands using a procedure similar to our experiment and asked participants to pay attention to only one of the two hands to detect changes in intensity without paying attention to the stimuli of the other hand. Results showed a modulation of the amplitude of the ERPs, in particular the components with lateralized scalp topography, suggesting a modulation of the responses of the cortical areas receiving inputs from the contralateral part of the body (Legrain et al., 2002). In order to clarify the cerebral underpinnings of the selective modulation of pain by FHA, future studies should

rely on similar paradigms as the ones developed in selective attention using neuroimaging or neurophysiology techniques.

Surprisingly, results of the present study were observed across the whole sample suggesting that the FHA suggestion was effective irrespective to the level of hypnotizability. This contrasts with previous studies that found FHA to be more effective among highly hypnotizable individuals (Benhaiem et al., 2001; Sharav & Tal, 2004, 2006). Several factors may explain this discrepancy. First, sample size of each group in this study (7 LH, 22 MH, 11 HH) was different than those of Sharav et al. (2006), mostly due to the absence of preselection for hypnotizability in our study. Second, previous studies either included only LH and HH participants and did not consider MH ones (Sharav & Tal, 2004, 2006) possibly contributing to divergent findings. Third, in contrast to several previous studies on FHA, no formal hypnotic induction was administered in the present protocol. According to Milling (2008), a suggestion delivered without prior induction may not constitute a truly hypnotic procedure, but rather what is referred to as an imaginative suggestion—a form of suggestion that relies more on cognitive engagement and imagery than on a distinct hypnotic state (Milling, 2008). This distinction is important, as imaginative suggestions tend to be more accessible to individuals across all levels of hypnotizability, potentially explaining the absence of group differences in the present study. Hence, the observed effect may reflect suggestion-based modulation of somatosensory experience rather than hypnosis per se. Nevertheless, the reported increase in the experience of dissociation does support the notion that FHA suggestions produced hypnosis-related effects.

Finally, our exploratory analyses revealed that among the four items measuring facets of the hypnotic experience, dissociation was significantly modulated *during* the FHA

suggestion, compared to *before* and *after*. This is consistent with findings from a study integrating hypnosis with virtual reality in which dissociation has been reported to be more sensitive to the hypnotic context than absorption or time perception (Rousseaux et al., 2023). Beyond its responsiveness to hypnotic suggestions, dissociation has also been shown to predict hypnotizability levels. For example, Vanhaudenhuyse et al. (2019) demonstrated that dissociation scores could reliably differentiate between high and low hypnotizable individuals (Vanhaudenhuyse et al., 2019), as defined by the Stanford Hypnotic Susceptibility Scale, Form C (SHSS C) (Weitzenhoffer & Hilgard, 1962). In the context of our study, this would suggest that greater dissociation during FHA might be associated with stronger pain modulation, as HH are known to benefit more from hypnotic suggestions than LH. However, our correlation analyses did not reveal any significant association between dissociation scores and pain modulation across timepoints (see Table 3 of supplementary material). This absence of relationship may be interpreted by the lack of interaction observed between hypnotizability and pain modulation (see above), possibly reflecting individual variability or methodological limitations due to the absence of a formal hypnotic induction. The lack of significant differences across timepoints for absorption and time perception items is also in line with Rousseaux et al. (2023), who similarly reported no modulation of these dimensions during virtual reality hypnosis. Although these measures were conceived based on the clinical and research experience of several experts (Vanhaudenhuyse et al., 2019), further research on the items of absorption and time perception needs to be conducted in order to identify the hypnotic conditions in which they show a modulation. Lastly, the item measuring automaticity was not modulated in our study (Polito et al., 2013; Rainville et al., 2019; Weitzenhoffer, 1974, 2002). This may be due to the absence of a formal hypnotic induction—used in prior studies

(e.g., Desmarteaux et al., 2021; Rainville et al., 2019)—which likely limited the depth of the hypnotic state achieved by participants.

The present study presents several limitations. First, for 13 participants out of 40, the average pain intensity rating was less than 50 prior to the FHA procedure meaning that a significant portion of the stimuli were not judged as painful by them. This could be due, on the one hand, to the upper limit of 70° during the pain threshold assessment, which would mean that such a temperature was not high enough to be clearly perceived as painful by some participants, and, on the other hand, to habituation related to the repetition of the heat stimuli. Accordingly, one could question the analgesic nature of the FHA procedure administered and the interpretation of the results. However, complementary analyses showed that the observed selective modulation of pain intensity and unpleasantness did not differ depending on whether the stimuli were perceived as painful prior to FHA. In this study, it could be argued that the suggestion produced hypoesthesia for some participants and hypoalgesia for others, depending on the initial presence or absence of pain.

Second, participants recruited in this study were not preselected based on their level of hypnotizability. One could argue that the lack of relationship between the observed effects and hypnotizability could be explained by this absence of preselection, as the distribution of hypnotizability levels have been uneven across the sample. From an ecological point of view, this choice aligns with the real-world clinical settings, where hypnotizability is not systematically assessed prior to hypnosis-based interventions. However, from an experimental perspective, preselection could be useful for identifying the potential generalizability of a given hypnotic procedure to broader population. Nevertheless, studies suggest that about 70 to 90% of the population falls in the moderate range of hypnotizability,

the rest being high or low responders (about 5 to 15% each) (Landry et al., 2017; Piccione et al., 1989; Polito et al., 2013; Register & and Kihlstrom, 1986; Weitzenhoffer, 1974, 2002). Interestingly, the sample in the present experiment exhibited similar proportions, suggesting that it was representative of the general population. This challenges the necessity of focusing on hypnotizability as a prerequisite in experimental research. Supporting this view, a meta-analysis by Montgomery et al. (2011) found that hypnotizability accounted for only 6% of the variance in clinical hypnosis outcomes, indicating that other factors likely play a more substantial role in determining the effectiveness.

To conclude, results of the present study demonstrate that focused hypnotic analgesia can selectively modulate pain intensity and unpleasantness at a targeted body location, without affecting the rest of the body. Future studies should investigate the underlying brain mechanisms responsible for this selective effect, in order to determine at which level of the neuronal processing nociceptive signals are modulated.

Acknowledgments:

We express our gratitude to Benvenuto Jacob and Dr Julien Lambert for their technical support and their assistance in coding the Matlab scripts related to the experiments.

Funding:

A.V.C., G.H. and V.L. are supported by the Funds for Scientific Research of the French-speaking Community of Belgium (F.R.S.-FNRS).

Disclosure statement:

The author(s) declare no conflicts of interest related to this work.

Generative AI tools (ChatGPT -3 & -4) have been used for sentence elaboration and rephrasing.

Data availability statement:

The authors confirm that the data supporting the findings of this study are available within the article and its supplementary materials. Additional information is available from the corresponding author upon reasonable request.

References:

Atlas, L. Y., & Wager, T. D. (2012). How expectations shape pain. *Neuroscience Letters*, *520*(2), 140-148. https://doi.org/10.1016/j.neulet.2012.03.039

Benhaiem, J.-M., Attal, N., Chauvin, M., Brasseur, L., & Bouhassira, D. (2001). Local and remote effects of hypnotic suggestions of analgesia. *Pain*, *89*(2), 167-173. https://doi.org/10.1016/S0304-3959(00)00359-6

Casiglia, E., Finatti, F., Tikhonoff, V., Stabile, M. R., Mitolo, M., Albertini, F., Gasparotti, F., Facco, E., Lapenta, A. M., & Venneri, A. (2020). Mechanisms of hypnotic analgesia explained by

functional magnetic resonance (fMRI). *International Journal of Clinical and Experimental Hypnosis*, *68*(1), 1-15. https://doi.org/10.1080/00207144.2020.1685331

De Pascalis, V., Cacace, I., & Massicolle, F. (2008). Focused analgesia in waking and hypnosis : Effects on pain, memory, and somatosensory event-related potentials. *Pain*, *134*(1), 197-208. https://doi.org/10.1016/j.pain.2007.09.005

De Pascalis, V., Magurano, M. R., & Bellusci, A. (1999). Pain perception, somatosensory event-related potentials and skin conductance responses to painful stimuli in high, mid, and low hypnotizable subjects : Effects of differential pain reduction strategies☆. *PAIN*, *83*(3), 499. https://doi.org/10.1016/S0304-3959(99)00157-8

De Pascalis, V., Magurano, M. R., Bellusci, A., & Chen, A. C. N. (2001). Somatosensory event-related potential and autonomic activity to varying pain reduction cognitive strategies in hypnosis. *Clinical Neurophysiology*, *112*(8), 1475-1485. https://doi.org/10.1016/S1388-2457(01)00586-7

Del Casale, A., Ferracuti, S., Rapinesi, C., De Rossi, P., Angeletti, G., Sani, G., Kotzalidis, G. D., & Girardi, P. (2015). Hypnosis and pain perception : An Activation Likelihood Estimation (ALE) meta-analysis of functional neuroimaging studies. *Journal of Physiology, Paris*, *109*(4-6), 165-172. https://doi.org/10.1016/j.jphysparis.2016.01.001

Denman, D. C. (2024). Hypnosis in Burn Care : Efficacy, Applications, and Implications for Austere Settings. *European Burn Journal*, *5*(3), Art. 3. https://doi.org/10.3390/ebj5030020

Desmarteaux, C., Streff, A., Chen, J.-I., Houzé, B., Piché, M., & Rainville, P. (2021). Brain Responses to Hypnotic Verbal Suggestions Predict Pain Modulation. *Frontiers in Pain Research*, *2*. https://doi.org/10.3389/fpain.2021.757384

Desmedt, J. E., & Robertson, D. (1977). Differential enhancement of early and late components of the cerebral somatosensory evoked potentials during forced-paced cognitive tasks in man. *The Journal of Physiology*, *271*(3), 761-782. https://doi.org/10.1113/jphysiol.1977.sp012025

Elkins, G. R., Barabasz, A. F., Council, J. R., & Spiegel, D. (2015). Advancing Research and Practice : The Revised APA Division 30 Definition of Hypnosis. *International Journal of Clinical and Experimental Hypnosis*, *63*(1), 1-9. https://doi.org/10.1080/00207144.2014.961870

Elkins, G. R., Johnson, A. K., Johnson, A. J., & Sliwinski, J. (2015). Factor Analysis of the Elkins Hypnotizability Scale. *International Journal of Clinical and Experimental Hypnosis*, *63*(3), 335-345. https://doi.org/10.1080/00207144.2015.1031550

Facco, E., Casiglia, E., Masiero, S., Tikhonoff, V., Giacomello, M., & Zanette, G. (2011). Effects of Hypnotic Focused Analgesia on Dental Pain Threshold : Enrico Facco, Edoardo Casiglia, Serena Masiero, Valery Tikhonoff, Margherita Giacomello und Gastone Zanette. *International Journal of Clinical and Experimental Hypnosis*, *59*(4), 454-468. https://doi.org/10.1080/00207144.2011.594749

Fardo, F., Allen, M., Jegindø, E.-M. E., Angrilli, A., & Roepstorff, A. (2015). Neurocognitive evidence for mental imagery-driven hypoalgesic and hyperalgesic pain regulation. *NeuroImage*, *120*, 350-361. https://doi.org/10.1016/j.neuroimage.2015.07.008

Forster, B., & Eimer, M. (2005). Covert attention in touch : Behavioral and ERP evidence for costs and benefits. *Psychophysiology*, *42*(2), 171-179. https://doi.org/10.1111/j.1469-8986.2005.00268.x

Forster, B., Tziraki, M., & Jones, A. (2016). The attentive homunculus : ERP evidence for somatotopic allocation of attention in tactile search. *Neuropsychologia*, *84*, 158-166. https://doi.org/10.1016/j.neuropsychologia.2016.02.009

Friederich, M., Trippe, R. H., Özcan, M., Weiss, T., Hecht, H., & Miltner, W. H. R. (2001). Laser-evoked potentials to noxious stimulation during hypnotic analgesia and distraction of attention suggest different brain mechanisms of pain control. *Psychophysiology*, *38*(5), 768-776. https://doi.org/10.1111/1469-8986.3850768

Gherri, E., White, F., & Venables, E. (2023). On the spread of spatial attention in touch : Evidence from event-related brain potentials. *Biological Psychology*, *178*, 108544. https://doi.org/10.1016/j.biopsycho.2023.108544

Jepma, M., Koban, L., van Doorn, J., Jones, M., & Wager, T. D. (2018). Behavioural and neural evidence for self-reinforcing expectancy effects on pain. *Nature Human Behaviour*, *2*(11), 838-855. https://doi.org/10.1038/s41562-018-0455-8

Kendrick, C., Sliwinski, J., Yu, Y., Johnson, A., Fisher, W., Kekecs, Z., & Elkins, G. (2016). Hypnosis for Acute Procedural Pain : A Critical Review. *International Journal of Clinical and Experimental Hypnosis*, *64*(1), 75-115. https://doi.org/10.1080/00207144.2015.1099405

Kuttner, L. (2012). Pediatric hypnosis : Pre-, peri-, and post-anesthesia. *Pediatric Anesthesia*, *22*(6), 573-577. https://doi.org/10.1111/j.1460-9592.2012.03860.x

Landry, M., Lifshitz, M., & Raz, A. (2017). Brain correlates of hypnosis : A systematic review and meta-analytic exploration. *Neuroscience & Biobehavioral Reviews*, *81*, 75-98. https://doi.org/10.1016/j.neubiorev.2017.02.020

Langlois, P., Perrochon, A., David, R., Rainville, P., Wood, C., Vanhaudenhuyse, A., Pageaux, B., Ounajim, A., Lavallière, M., Debarnot, U., Luque-Moreno, C., Roulaud, M., Simoneau, M., Goudman, L., Moens, M., Rigoard, P., & Billot, M. (2022). Hypnosis to manage musculoskeletal and neuropathic chronic pain : A systematic review and meta-analysis. *Neuroscience and Biobehavioral Reviews*, *135*, 104591. https://doi.org/10.1016/j.neubiorev.2022.104591

Legrain, V., Guérit, J.-M., Bruyer, R., & Plaghki, L. (2002). Attentional modulation of the nociceptive processing into the human brain : Selective spatial attention, probability of stimulus occurrence, and target detection effects on laser evoked potentials. *PAIN*, *99*(1), 21. https://doi.org/10.1016/S0304-3959(02)00051-9

Lejeune, N., Petrossova, E., Frahm, K. S., & Mouraux, A. (2023). High-speed heating of the skin using a contact thermode elicits brain responses comparable to CO2 laser-evoked potentials. *Clinical Neurophysiology*, *146*, 1-9. https://doi.org/10.1016/j.clinph.2022.11.008

Merz, A. E., Campus, G., Abrahamsen, R., & Wolf, T. G. (2022). Hypnosis on acute dental and maxillofacial pain relief : A systematic review and meta-analysis. *Journal of Dentistry*, *123*, 104184. https://doi.org/10.1016/j.jdent.2022.104184

Michie, P. T. (1984). Selective Attention Effects on Somatosensory Event-Related Potentials. *Annals of the New York Academy of Sciences*, *425*(1), 250-255. https://doi.org/10.1111/j.1749-6632.1984.tb23542.x

Michie, P. T., Bearparic, H. M., Crawford, J. M., & Glue, L. C. T. (1987). The Effects of Spatial Selective Attention on the Somatosensory Event-Related Potential. *Psychophysiology*, *24*(4), 449-463. https://doi.org/10.1111/j.1469-8986.1987.tb00316.x

Milling, L. S. (2008). Is high hypnotic suggestibility necessary for successful hypnotic pain intervention? *Current Pain and Headache Reports*, *12*(2), 98-102. https://doi.org/10.1007/s11916-008-0019-0

Mima, T., Nagamine, T., Nakamura, K., & Shibasaki, H. (1998). Attention Modulates Both Primary and Second Somatosensory Cortical Activities in Humans : A Magnetoencephalographic Study. *Journal of Neurophysiology*, *80*(4), 2215-2221. https://doi.org/10.1152/jn.1998.80.4.2215

Oldfield, R. C. (1971). The assessment and analysis of handedness : The Edinburgh inventory. *Neuropsychologia*, *9*(1), 97-113. https://doi.org/10.1016/0028-3932(71)90067-4

Paqueron, X., Musellec, H., Virot, C., & Boselli, E. (2019). Hypnotic Glove Anesthesia Induces Skin Temperature Changes in Adult Volunteers : A Prospective Controlled Pilot Study. *International Journal of Clinical and Experimental Hypnosis*, *67*(4), 408-427. https://doi.org/10.1080/00207144.2019.1649544

Piccione, C., Hilgard, E. R., & Zimbardo, P. G. (1989). On the Degree of Stability of Measured Hypnotizability Over a 25-Year Period. *Journal of Personality and Social Psychology*, *56*(2), 289-295. Scopus. https://doi.org/10.1037/0022-3514.56.2.289

Polito, V., Barnier, A. J., & Woody, E. Z. (2013). Developing the Sense of Agency Rating Scale (SOARS) : An empirical measure of agency disruption in hypnosis. *Consciousness and Cognition*, *22*(3), 684-696. https://doi.org/10.1016/j.concog.2013.04.003

Provençal, S.-C., Bond, S., Rizkallah, E., & El-Baalbaki, G. (2018). Hypnosis for burn wound care pain and anxiety : A systematic review and meta-analysis. *Burns: Journal of the International Society for Burn Injuries*, *44*(8), 1870-1881. https://doi.org/10.1016/j.burns.2018.04.017

Rainville, P., Streff, A., Chen, J.-I., Houzé, B., Desmarteaux, C., & Piché, M. (2019). Hypnotic Automaticity in the Brain at Rest : An Arterial Spin Labelling Study. *International Journal of Clinical and Experimental Hypnosis*, *67*(4), 512-542. https://doi.org/10.1080/00207144.2019.1650578

Register, P. A., & and Kihlstrom, J. F. (1986). Finding the Hypnotic Virtuoso. *International Journal of Clinical and Experimental Hypnosis*, *34*(2), 84-97. https://doi.org/10.1080/00207148608406974

Rousseaux, F., Panda, R., Toussaint, C., Bicego, A., Niimi, M., Faymonville, M.-E., Nyssen, A.-S., Laureys, S., Gosseries, O., & Vanhaudenhuyse, A. (2023). Virtual reality hypnosis in the management of pain : Self-reported and neurophysiological measures in healthy subjects. *European Journal of Pain (London, England)*, *27*(1), 148-162. https://doi.org/10.1002/ejp.2045

Sambo, C. F., & Forster, B. (2011). Sustained Spatial Attention in Touch : Modality-Specific and Multimodal Mechanisms. *The Scientific World Journal*, *11*(1), 613624. https://doi.org/10.1100/tsw.2011.34

Sharav, Y., & Tal, M. (2004). Focused analgesia and generalized relaxation produce differential hypnotic analgesia in response to ascending stimulus intensity. *International Journal of Psychophysiology*, *52*(2), 187-196. https://doi.org/10.1016/j.ijpsycho.2003.10.001

Sharav, Y., & Tal, M. (2006). Focused hypnotic analgesia : Local and remote effects. *Pain*, *124*(3), 280-286. https://doi.org/10.1016/j.pain.2006.04.016

Sinclair, H. B., R. J. (2000). Tactile-spatial and cross-modal attention effects in the primary somatosensory cortical areas 3b and 1-2 of rhesus monkeys. *Somatosensory & Motor Research*, *17*(3), 213-228. https://doi.org/10.1080/08990220050117574

Sine, H., Achbani, A., & Filali, K. (2022). The Effect of Hypnosis on the Intensity of Pain and Anxiety in Cancer Patients : A Systematic Review of Controlled Experimental Trials. *Cancer Investigation*, *40*(3), 235-253. https://doi.org/10.1080/07357907.2021.1998520

Tefikow, S., Barth, J., Maichrowitz, S., Beelmann, A., Strauss, B., & Rosendahl, J. (2013). Efficacy of hypnosis in adults undergoing surgery or medical procedures : A meta-analysis of randomized controlled trials. *Clinical Psychology Review*, *33*(5), 623-636. https://doi.org/10.1016/j.cpr.2013.03.005

Thompson, T., Terhune, D. B., Oram, C., Sharangparni, J., Rouf, R., Solmi, M., Veronese, N., & Stubbs, B. (2019). The effectiveness of hypnosis for pain relief : A systematic review and meta-analysis of 85 controlled experimental trials. *Neuroscience & Biobehavioral Reviews*, *99*, 298-310. https://doi.org/10.1016/j.neubiorev.2019.02.013

Tiberghien, G. (1984). *Initiation à la psychophysique*. P.U.F.

Vanhaudenhuyse, A., ledoux, D., Gosseries, O., Demertzi, A., Laureys, S., & Faymonville, M.-E. (2019). Can subjective ratings of absorption, dissociation, and time perception during « neutral hypnosis » predict hypnotizability? : An exploratory study. *International Journal of Clinical and Experimental Hypnosis*, *67*(1), 28-38. https://doi.org/10.1080/00207144.2019.1553765

Vanhaudenhuyse, A., Nyssen, A.-S., & Faymonville, M.-E. (2020). Recent Insight on How the Neuroscientific Approach Helps Clinicians. *OBM Integrative and Complementary Medicine*, *5*(2), Art. 2. https://doi.org/10.21926/obm.icm.2002028

Virot, C., & Bernard, F. (2018). *Hypnose, douleurs aiguës et anesthésie (2e édition)*. Arnette - John Libbey Eurotext.

Weitzenhoffer, A. M. (1974). When is an "instruction" an "instruction"? *International Journal of Clinical and Experimental Hypnosis*, *22*(3), 258-269. https://doi.org/10.1080/00207147408413005

Weitzenhoffer, A. M. (2002). Scales, Scales and More Scales. *American Journal of Clinical Hypnosis*, *44*(3-4), 209-219. https://doi.org/10.1080/00029157.2002.10403481

Weitzenhoffer, A. M., & Hilgard, E. R. (s. d.). *STANFORD HYPNOTIC SUSCEPTIBILITY SCALE, FORM C*.

Zachariae, R., & Bjerring, P. (1994). Laser-Induced Pain-Related Brain Potentials and Sensory Pain Ratings in High and low Hypnotizable Subjects During Hypnotic Suggestions of Relaxation, Issociated Imagery, Focused Analgesia, and Placebo. *International Journal of Clinical and Experimental Hypnosis*, *42*(1), 56-80. https://doi.org/10.1080/00207149408409341

Figure captions:

Figure 1. Time course of the experiment. Before the experimental phase, stimulus temperature was determined for each participant using the method of limits. The experimental session consisted of three timepoints: *before*, *during* and *after*. During each block, 20 stimuli were applied randomly and equally between the two forearms of the participant, followed by the assessment of four items characterizing the hypnotic experience: absorption, dissociation, time perception and automaticity. Between timepoints *before* and *during*, FHA was induced using the protective glove technique. Between the timepoints *during* and *after*, FHA was ended by removing the glove. After the experimental phase, participants completed the Edinburgh Handedness Inventory (EHI) (Oldfield, 1971) and measure of their hypnotizability was assessed using the Elkins Hypnotizability scale (EHS) (Elkins, Barabasz, et al., 2015; Elkins, Johnson, et al., 2015; Kendrick et al., 2016) .

Figure 2. Boxplots representing pain intensity ratings for the protected (blue) and unprotected (red) arms across the three times points (before, during and after). The boxes represent the interquartile range (IQR) with the thick internal line representing the median of the data, the upper side the first quartile (Q1) and the lower side the third quartile (Q3). The dots represent the mean values of each participant with the thin grey lines connecting the values of the protected and unprotected arms of a same participant for each time condition. Unconnected dots of a given arm and timepoint are the outliers (< (Q1 - 1.5*IQR) or > (Q3 +1.5*IQR), and those were included in the calculation of the quartiles. The group-averaged mean values of each condition are illustrated by the grey triangles. Significance levels are indicated with asterisks (** $p \leq .01$, *** $p \leq .001$). Pain intensity ratings of the protected arm are significantly smaller during as compared to before and after FHA. Pain intensity is also significantly smaller for the *protected* arm as compared to the *unprotected* one, only at the timepoint *during*.

Figure 3. Mean change in pain intensity perception between the different timepoints. Change in pain intensity is computed by subtracting ratings between different timepoints. *Before-During* corresponds to the subtraction of pain intensity ratings for timepoint *during* to those of timepoint *before* for each subject and each arm. The higher is the value, the greater is the reduction of pain from *before* to *during*. *After-During* corresponds to the subtraction of pain intensity *during* to the perception *after*. The higher is the value, the greater is the increase between *during* and *after*. *Before-After* corresponds to the subtraction of the timepoint *after* to the timepoint *before*. The higher is the value, the greater is the intensity *before* compared to *after*. Errors bars represent 95% confidence intervals of each condition. Significant differences are indicated with asterisks (*** $p \leq .001$).

Figure 4. Boxplots representing pain unpleasantness ratings for the *protected* (blue) and *unprotected* (red) arms across the three timepoints (*before*, *during* and *after)*. The boxes represent the interquartile range (IQR) with the thick internal line illustrating the median of the data, the upper side the first quartile (Q1) and the lower side the third quartile (Q3). The dots represent the mean values of each participant with the thin grey lines connecting the values of the protected and unprotected arms of a same participant for each time condition. Unconnected dots of a given arm and timepoint are the outliers (< (Q1 - 1.5*IQR) or > (Q3 +1.5*IQR), and those were included in the calculation of the quartiles. The group-averaged mean values of each condition are illustrated by the grey triangles. Significance levels are indicated with asterisks (** $p \leq .01$, *** $p \leq .001$). Pain unpleasantness ratings of the protected arm are significantly smaller during as compared to before and after FHA. Pain intensity is also significantly smaller for the *protected* arm as compared to the *unprotected* one, only at the timepoint *during*.

Figure 5. Mean change in pain unpleasantness perception between the different timepoints. Change in pain unpleasantness is computed by subtracting ratings between different time points. *Before-During* corresponds to the subtraction for each subject and each arm of the ratings *during* to the those *before*. The higher is the value, the greater is the reduction of unpleasantness from *before* to *during*. *After-During* corresponds to the subtraction of the ratings of *during* to the ones of *after*. The higher is the value, the greater is the increase of unpleasantness between *during* and *after*. *Before-After* corresponds to the subtraction of the timepoint *after* to the timepoint *before*. The higher is the value, the greater is the perception of unpleasantness *before* compared to *after*. Errors bars represent 95% confidence intervals for each condition. Significant differences are indicated with asterisks (** $p \leq .01$, *** $p \leq .001$).

Figure 6. Boxplots representing the 4 items *dissociation*, *absorption*, *automaticity* and *time perception* at the 3 timepoints *before*, *during* and *after* FHA. Boxplots represent the interquartile range (IQR) with the first quartile (Q1), median and third quartile (Q3). The isolated dots (not connected to the other ones of a given timepoint) are the outliers (< (Q1 -1.5*IQR) or > (Q3 +1.5*IQR), and those were included in the calculation of the quartiles. Significant differences are indicated with asterisks (** $p \leq .01$, *** $p \leq .001$). Only *dissociation* significantly differs between the different timepoints, increasing *during* FHA as compared to before and after.