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Effects of aging on experimentally induced pain perception during a distraction task

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To investigate the effects of psychological (anxiety, depression, pain catastrophizing) aspects, pain sensitivity, cognitive performance and executive functions, on pain perception during a distraction task in an acute pain laboratory in young and elderly adults. Twenty-six young (age: 20.0 ± 1.6 years) and thirty-three elderly (age: 68.0 ± 3.8 years) adults completed four self-reported questionnaires (Hospital Anxiety and Depression Scale—HADS, Pain Anxiety Symptoms Scale-20—PASS/20, Pain Catastrophizing Scale—PCS, and Pittsburgh Sleep Quality Index—PSQI), pressure pain thresholds (PPTs), a battery of executive functions (working memory, cognitive flexibility, mental inhibition), and attention levels before performing two distraction tasks (1-back, 2-back). Pain was experimentally induced with a thermal stimulus applied at the non-dominant forearm to provoke moderate pain (70/100 points) before and during the distraction tasks. Age (young, elderly), psychological and psychophysical variables, and neurocognitive test performance levels (low, medium, high) were included in separate ANCOVAs to compare pain intensity at baseline and during distraction tasks. All ANOVAs revealed a main effect of distraction task, indicating that perceived pain intensity scores were lower during both distraction tasks ($p < 0.001$) compared to baseline. Overall, there was no significant effect of age on perceived pain intensity after distraction tasks, except for an interaction effect between the distraction task and age group depending on PPTs levels ($F [2,49] = 3.7$, $p = 0.03$). Elderly adults (with higher PPTs) reported lower perceived pain intensity during both distraction tasks compared to younger adults (lower PPTs). This study found that the hypoalgesic effect of a distraction task is not directly associated with age or neurocognitive function and attention levels in pain-free subjects, but it was related with higher PPTs (lower pressure pain hyperalgesia).

Keywords Distraction task, Pain, Pressure pain, Cognition, Attention, Executive function

Pain is the most common reason for patients to seek medical attention, and inadequate evaluation can potentially lead to less-than-optimal treatment outcomes[1]. By 2012, the estimated annual cost of pain in the United States of America ranged from $560 billion to $635 billion, imposing a significant burden on the nation's healthcare system and economy[2]. This issue is critical as research highlights the long-term negative effects of untreated chronic pain, such as adverse neuroendocrine responses, disrupted sleep patterns, and heightened sensitivity to pain[3]. Therefore, it is essential to increase the current understanding of the factors influencing pain perception and to ensure effective management.

Pain is a complex experience influenced by biological, psychological, and social factors. Multidimensional pain models suggest that thoughts, emotions, and behaviors can influence how people perceive pain, explaining the variation in individual pain experiences[4]. However, the understanding of pain in older adults remains

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limited[5]. With life expectancy steadily increasing, there is growing interest among clinicians and researchers in how aging affects pain processing, pain perception and pain modulation[6].

Older age seems to be associated with higher pain thresholds and reduced effectiveness of internal pain inhibition mechanisms[7,8]. Thus, several studies have focused on age-related brain changes that influence pain processing. The prefrontal cortex (PFC) is a brain region involved in the top-down regulation of pain[9–11], and it is susceptible to age-related reductions in gray matter volume[12]. Evidence indicates that individual differences in frontal functioning influence the effectiveness of endogenous pain modulation[12–16]. Specifically, cognitive inhibition is strongly linked to endogenous modulation of pain[12,15,16]. Additionally, research has emphasized the importance of other executive functions, different than cognitive inhibition, in the pain experience[17]. In fact, poorer performance on executive functioning tasks such as working memory and selective attention has been shown to be associated with higher pain levels[17].

Executive functions encompass cognitive processes such as planning, initiation, shifting, monitoring, and inhibiting behaviors. These functions are mainly mediated by the frontal lobes, particularly the PFC, which orchestrates complex behaviors through extensive connections with other brainstem regions[18]. The link between pain and executive functions likely stems from overlapping neural networks within the PFC[19,20]. Studies suggest that heightened cognitive inhibition, a key aspect of executive functions, correlates with reduced pain sensitivity[21,22]. However, whether this correlation extends to other executive functions has not been extensively investigated. Factor analyses of neuropsychological and experimental executive function tests have identified three main components: updating and monitoring working memory (Updating), shifting between tasks (Shifting), and inhibiting automatic responses (Inhibition)[17]. These components explain a significant portion of variance in executive function, yet a comprehensive examination of how these functions relate to experimental-induced pain experiences is currently lacking[23].

Distraction is a common psychological technique used to alleviate pain, particularly among individuals with chronic pain[24]. It works by directing attention away from the pain towards other stimuli, thereby engaging competing demands[25,26]. However, its effectiveness in managing acute pain has not been well-established and varies across studies[27] as some authors report significant pain relief[28,29], others minimal effects[30], and some no effects[31]. These discrepancies may arise from differences in study design and conditions. Current research suggests that within-individual differences in executive functions, particularly cognitive inhibition skills can play a role in pain perception[21,22,32] and may mitigate pain-related disruptions during task performance. Nevertheless, the influence of cognitive inhibition on the efficacy of distraction tasks as a pain management strategy considering aging remains uncertain[27,33].

To address this gap and to explore the impact of executive functioning on pain perception across different age groups, the current study investigated if psychological (anxiety, depression, pain catastrophizing), psychophysical (pressure pain sensitivity) and cognitive (executive function and cognitive performance) variables influence pain perception during distraction tasks in an acute pain laboratory in youth and elderly adults. We hypothesized that older adults would exhibit a higher pain reduction during the distraction tasks than younger adults.

Methods

Study design

This experimental study employed a 2 × 3 × 2 mixed factorial design with three independent variables. The first independent variable (within-subject factor) was the type of distraction task (1-back and 2-back tasks). The second independent variable (between-subject factor) categorized subjects based on their performance on neurocognitive tests into three levels: low, medium, and high. The third independent variable (between-subject factor) was age: young (from 18 to 30 years old) and elderly (from 60 to 75 years old) adults. The dependent variable was the perceived pain intensity at baseline and during both 1-back and 2-back distraction tasks.

Participants

Healthy adults recruited voluntarily through bulletin board announcements at Universidad Rey Juan Carlos, Madrid, and via social media were invited to participate. Exclusion criteria included: (a) psychosis or major psychiatric disorders; (b) use of tricyclic antidepressants (≥ 50 mg/day amitriptyline or equivalent) or psychoactive medications; (c) infectious, metabolic, renal, endocrine, neuromuscular, oncological diseases: (d) history of chronic pain; (e) surgery in the past decade; (f) pregnancy or lactation; (g) mental disability; (h) cognitive or sensory disorders; (i) caffeine consumption within 2 h before the test; (j) intense physical activity on the test day; (k) lack of consent to participate in the study; or (l) a Mini-Mental State Examination (MMSE) score below 27 points[34]. The MMSE, a brief screening tool for cognitive function, covers orientation, attention, calculation, memory, and language, and scores of 27/30 or higher are considered normal[34].

The study received approval from the Ethics Committee of Universidad Rey Juan Carlos (URJC 1909202332123) and adhered to the Declaration of Helsinki guidelines. All participants provided written informed consent.

Sample size calculation

The authors anticipated a medium effect size of f = 0.25, a set alpha = 0.05 and a target power = 0.80, with six groups to be compared using a repeated measures analysis of variance (ANOVA) analysis. Accordingly, using G*Power software v.3.1.9.2 (Düsseldorf, Germany), a sample size of 54 participants was required.

Psychological variables

The Hospital Anxiety and Depression Scale (HADS) assesses anxiety and depressive symptoms by using a 14-item, 4-point Likert scale[35]. The Spanish version by Tejero et al.[36] was used in the current study since it mirrored the original's 2-factor structure: HADS-A (anxiety, 7 items) and HADS-D (depression, 7 items).

The Spanish version of the Pain Catastrophizing Scale (PCS)[37,38] evaluates catastrophic thinking related to anticipated pain. The 13-item PCS uses a 5-point Likert scale, covering three subscales for magnification (3 items), rumination (4 items), and helplessness (6 items)[39].

The short version of the Pain Anxiety Symptoms Scale-20 (PASS-20) measures pain anxiety through a 20-item scale assessing cognitive anxiety, avoidance, and escape behaviors, fear of pain, and physiological anxiety using a 6-point Likert scale[40].

The Pittsburgh Sleep Quality Index (PSQI)[41] assesses sleep quality through 19 items, yielding a total score (0–21 points). The PSQI is reliable and valid for measuring sleep disturbances[41].

Executive functions

Several studies had identified that working memory, mental inhibition, and cognitive flexibility are those executive functions showing the highest relevance for pain perception[23,42–44].

Working memory was assessed by using the "D/R/I Digits" subtest from the Wechsler Adult Intelligence Scale (WAIS-IV)[45]. This subtest evaluates immediate and working memory, reflecting sequencing skills, planning, alertness, and cognitive flexibility. It consists of three tasks: Forward Digit Span (repeating a series of digits in the presented order), Backward Digit Span (repeating digits in reverse order), and Sequencing Digit Span (repeating numbers in ascending order as read by the examiner).

Mental inhibition and cognitive flexibility were measured with the "response inhibition index" from the Five Digit Test (FDT), a task similar to the Stroop test[46]. The FDT includes four sequential parts: reading, counting, choice, and alternation, each with 50 items, and varies in complexity to evaluate executive functions. The reading and counting parts evaluate automatic and simple processes, while the alternation and choice parts assess complex processes requiring active mental control and slowing response speed. The scores include Decoding_FDT (time in seconds to read all numeric items), Retrieving_FDT (time in seconds to read all non-numeric items like asterisks), Inhibiting_FDT (time in seconds to read identical numeric items), and Shifting_FDT (time in seconds to read numeric items mixed with other numeric items within a box). Frome these data, response inhibition and mental flexibility can be derived[46].

Attention assessment

Attention has been found to also be a relevant cognitive process in the pain experience[29,47–49]. Therefore, selective attention and mental concentration were measured with the Spanish version of the D2 attention test[50,51], involving 14 lines of 47 characters each, totaling 658 elements. Subjects identified relevant 'd' characters with two dashes within 20 s per line. Scores included total responses (TR), correct responses (TA), omissions responses (O), commissions (C), test effectiveness (TOT), concentration index (CON), highest and lowest elements tested (TR+ and TR−), and variation index (VAR).

Pressure pain sensitivity

The pressure pain threshold (PPT), defined as the minimal pressure at which a sensation of pressure transitions to discomfort[52], was measured by using an electronic algometer (Somedic AB, Farsta, Sweden) in kilopascals (kPa). This device features a 1 cm^2 rubber-tipped plunger attached to a force transducer. Pressure was applied at a rate of 30 kPa/s. Participants were instructed to press the stop switch of the algometer when they felt the applied pressure turned into a first sensation of discomfort. The average of three trials was calculated for analysis, with a 30-s rest between measures. Pressure pain sensitivity was measured at the C5–C6 joint (cervical spine), between the II and III metacarpals (hand), and in the tibialis anterior muscle (leg), in random order to avoid sequencing bias[53].

Distraction tasks

Distraction tasks are strategies commonly used to reduce pain perception since they divert attention from the painful stimulus by refocusing attention on another task[28,43,48]. In the current study, two n-back tasks were employed as a distraction. These tasks involve a sequence of letters or numbers presented in a row, where participants must identify if the current stimulus matches the one seen a certain number of steps earlier (e.g., 1-back, 2-back, 3-back, etc.). For this study, both 1-back and 2-back tasks were programmed using E-prime 3.0 software, each consisting of 10 series with 21 letters. In the 1-back task, participants pressed "1" for 'yes' and "2" for 'no' to indicate if each letter matched the previous one. In the 2-back task, subjects checked if each letter matched the one seen in two previous trials. Each letter was displayed for 840 ms, preceded by a 1000-ms fixation cross[43]. Each series included 30% repeating letters, with no more than three consecutive repetitions, and the duration of each series was synchronized with the duration of the painful stimulation.

Study procedure

Participants who satisfied eligibility criteria were evaluated at the experimental clinical psychology laboratory of Universidad Rey Juan Carlos between October 2023 and March 2024. They completed neuropsychological tests assessing working memory, mental inhibition, cognitive flexibility, and attention during an evaluation taking about 20 min (Table 1).

First, a pain stimulus calibration task was performed to induce moderate pain levels in the participants, defined as a score of 70 out of 100 mm on a computerized visual analog pain scale (CoVAS). A 30 × 30 mm thermode was placed on the non-dominant forearm, 15 cm proximal to the wrist[54]. Heat stimuli were applied with a Thermotest System (Somedic AB®, Sweden) by using a "ramp and hold" procedure, starting at 32 °C for 3 s, increasing by 0.7 °C until reaching a temperature able to induce moderate pain (70/100 on the CoVAS)[43,44]. This temperature was held for 15 s, then decreased by 8 °C to return to 32 °C, followed by a 30-s rest before the next thermal stimulus. Participants were instructed to press the stop button when the temperature reached

Cognitive domains	Neuropsychological tests	Outcomes	Method of administration
Cognitive screening	MMSE	Cognitive status	Auditory/visual/manual (paper)
Short term and working verbal memory	Digit span forward (WAIS-IV)	Span of digits	Auditory/oral
	Digit span backward (WAIS-IV)	Auditory working memory	
	Digit span sequencing (WAIS-IV)	Auditory working memory	
Selective attention	D2 test of attention	D2_TR	Visual/manual (paper)
		D2_TA	
		D2_TOT	
		D2_CON	
		D2_VAR	
		D2_O	
		D2_C	
Mental inhibition and cognitive flexibility	Five digits test FDT	Decoding_FDT	Visual/oral
		Retrieving_FDT	
		Inhibiting_FDT	
		Shifting_FDT	

Table 1. Cognitive domains and neuropsychological tasks. *MMSE* Mini-Mental Scale Examination, *WAIS-IV* Wechsler Intelligence Scale for Adults-IV, *D2_TR* total number of items answered, *D2_TA* number of items answered correctly, *D2_O* errors of omission committed, *D2_C* commission errors made, *D2_TOT* number of elements processed minus the total number of errors committed, *D2_CON* number of relevant elements marked minus the number of commissions, *D2_VAR* variation index, *DSF* Digit Span Forward, *DSB* Digit Span Backward, *DSS* Digit Span Sequencing, *Decoding_FDT* time in seconds to read all numeric-items, *Retrieving_FDT* time in seconds to read all non-numeric items, *Inhibiting_FDT* time in seconds to read numeric items, *Shifting_FDT* time in seconds to read non-numeric items.

provoked that level of pain (70/100 on the CoVAS). The pain stimulus calibration task continued until three consecutive pain intensity scores of approximately 70 were reached. The final thermal stimulus was obtained from the average of the three scores. In the current study, the mean temperature of the thermal stimulus needed for inducing moderate pain in the group of young people was 46.6 (SD: 1.15) °C whereas that in the group of elderly people was 46.2 (SD: 1.2) °C ($t = 1.290$; $p = 0.202$).

Subsequently, participants were trained to perform distraction tasks, including 1-back and 2-back tasks, involving complex executive functions like working memory[29]. They underwent a brief training session of three series on each task, receiving visual feedback and aiming for at least 80% accuracy. Participants then experienced two sets of ten painful stimuli, identical to those used in the pain stimulus calibration task, each lasting about 30 s. During the first set, they performed 10 trials of the 1-back task, and during the second set, they performed 10 trials of the 2-back task. After each pain stimulus, participants rated their perceived pain intensity using the CoVAS scale from 0 to 100.

The entire experimental procedure lasted 90 min for each participant and was conducted by a skilled clinical neuropsychologist.

Statistical analysis

All statistical analyses were conducted using SPSS 27 Statistical Software. Outliers were identified through boxplots, considering values below the first quartile minus 1.5 times the interquartile range and above the third quartile plus 1.5 times the interquartile range as potential outliers, though none were found. The Kolmogorov–Smirnov test was used to check for normality, and all data were normally distributed.

Descriptive and frequency analyses were carried out for sociodemographic, psychological, PPTs, and neurocognitive variables. Chi-square (for categorical variables) and *t*-test independent samples analyses (for continuous variables) were conducted to calculate intergroup differences by age (young, elderly) in sociodemographic, psychological, PPTs, and cognitive variables to identify potential covariates to be included in posterior analyses. Both groups (young or elderly subjects) differed significantly in sex, educational level, marital status, employment status, anxiety levels, pain anxiety, D2_TOT raw scores, and PPTs at all sites; accordingly, they were included as those covariates in the main analyses.

Subsequently, two separated analyses of repeated-measures ANCOVA were performed to assess the effect of age over perceived pain intensity while performing the 1-back and 2-back distraction tasks by controlling potential confounders. For both analyses, perceived pain intensity (baseline, 1-back, 2-back) was the within-subject factor, and age group (young and elderly) was the independent variable. In the first analysis, sociodemographic (age, sex, educational level, marital status, employment status) and psychological (anxiety and pain anxiety) variables were the included covariates, whereas in the second analysis, PPTs (three levels: C5–C6, hand, tibialis anterior) were the cofounder covariates.

Finally, separated four repeated-measures ANOVA analyses were conducted to examine the impact of neurocognitive test performance level and age group on perceived pain intensity during 1-back and 2-back tasks. For these analyses, only the D2_TOT raw scores were used. Based on tests manual interpretation, centile scores of these neurocognitive tests were classified as low, medium, and high levels. Thus, perceived experimentally induced pain intensity (baseline, 1-back, and 2-back) was the within-subject factor, while neurocognitive test performance levels (low, medium and high) and age group (young, elderly) were the independent variables. Assumptions of normality and sphericity were checked and satisfactorily met. Thus, due to the inclusion of five main groups (two age groups and three neurocognitive levels) in the analysis, we applied the correction for multiple comparison and considered a P value < 0.01 (0.05/5) as statistically significant. Finally, partial eta squared (n^2p) was used to calculate effect sizes, with values of 0.01 indicating a small effect, 0.06 a medium effect, and above 0.14 a large effect[55]. Bonferroni post hoc tests were applied to identify intergroup differences.

Results

Descriptive data and intergroup comparisons

Descriptive data and intergroup comparisons can be seen in Table 2. Chi-square analyses revealed significant differences in sex ($\chi^2 = 5.9$, $p = 0.01$), marital status ($\chi^2 = 59.0$, $p < 0.001$), educational level ($\chi^2 = 11.4$, $p = 0.001$), and employment status ($\chi^2 = 55.7$, $p < 0.001$) between age groups. Likewise, *t*-test independent samples also found significant differences where young adults had lower age (mean difference: − 49.0, 95% CI − 50.6 to − 47.3), lower PPTs (higher hyperalgesia to pressure pain) at C5-C6 (mean difference: − 86.5 kPa, 95% CI − 123.9 to − 49.1), leg (mean difference: − 182.1 kPa, 95% CI − 283.2 to − 80.9) and hand (mean difference: − 102.4 kPa, 95% CI − 154.0 to − 50.7), but higher anxiety (mean difference: 2.0, 95% CI 0.4 to 3.6), pain anxiety (mean difference: 8.7, 95%

	Young subjects (*n* = 26)	Elderly subjects (*n* = 33)		
	n (%)	*n* (%)	χ^2	*p*
Sex*			5.9	0.01
Male	6 (23.1%)	18 (54.5%)		
Female	20 (76.9%)	15 (45.5%)		
Marital status**			59.0	0.001
Single	26 (100%)	0 (0%)		
Married	0 (0%)	25 (75.8%)		
Divorced	0 (0%)	4 (12.1%)		
Widowed	0 (0%)	4 (12.1%)		
Educational level**			11.4	0.001
Primary	0 (0%)	1 (3%)		
Secondary	25 (96.2%)	19 (57.6%)		
Higher education	1 (3.8%)	13 (39.4%)		
Employment status**			55.7	0.001
Student	25 (96.2%)	0 (0%)		
Working	1 (3.8%)	4 (12.1%)		
Unemployed	0 (0%)	28 (84.8%)		
Retired	0 (0%)	1 (3%)		
	Mean (SD)	**Mean (SD)**	**t**	***p***
Age**	20.0 (1.6)	68.0 (3.8)	− 65.7	0.001
Anxiety (HADS-A, 0–21)*	7.6 (3.4)	5.6 (2.8)	2.5	0.01
Depression (HADS-D, 0–21)	3.6 (2.6)	2.8 (2.2)	1.1	0.23
Pain catastrophizing (PCS, 0–52)	16.5 (8.3)	15.2 (9.6)	0.52	0.60
Pain anxiety (PASS-20, 0–100)**	32.1 (12.3)	23.3 (10.4)	2.9	0.001
Sleep quality (PSQI, 0–21)	7.8 (3.0)	7.0 (3.7)	0.79	0.42
Mental inhibition (Inhibiting_FDT)	17.8 (8.8)	16.4 (5.4)	0.74	0.45
Cognitive flexibility (Shifting_FDT)	26.2 (13.3)	29.7 (8.4)	− 1.2	0.21
Selective attention (D2_TOT)**	466.8 (52.0)	333.5 (70.4)	8.0	0.001
Working memory (D/R/I digits)	25.3 (5.5)	22.9 (5.4)	1.6	0.10
PPTs C5-C6 (kPa)**	172.5 (60.7)	259.0 (71.6)	− 4.6	0.001
PPTs Tibialis anterior (kPa)**	390.9 (136.9)	573.0 (216.6)	− 3.6	0.001
PPTs Hand (kPa)**	246.8 (68.5)	349.2 (106.3)	− 3.9	0.001

Table 2. Comparison of sociodemographic, psychological, PPTs, and cognitive variables between young and elderly adults. *n* number of subjects, % percentage of subjects, *SD* standard deviation, *$p < 0.01$; **$p < 0.001$. *HADS-A* Hospital Anxiety and Depression Scale (Anxiety), *HADS-D* Hospital Anxiety and Depression Scale (Depression), *PCS* Pain Catastrophizing Scale, *PASS-20* Pain Anxiety Symptoms Scale-20, *PSQI* The Pittsburgh Sleep Quality Index, *FDT* Five Digits Test, *D2* D2 Test of Attention, *D/R/I Digits* Working memory subtest of the Wechsler Adult Intelligence Scale battery.

Groups						
	Young adults ($n = 26$)	Elderly adults ($n = 33$)	Univariate tests			
Perceived pain intensity	Mean (SD)	Mean (SD)	F	p	n^2p	β-1
Baseline	70.0 (0.0)	70.0 (0.0)				
1-back	53.1 (28.5)	37.0 (36.1)	0.06	0.80	0.00	0.05
2-back	51.4 (25.9)	29.2 (32.7)	0.14	0.70	0.00	0.06

Table 3. Estimated marginal means and standard deviations (SD) controlling for sociodemographic and psychological variables.

Groups						
	Young adults ($n = 26$)	Elderly adults ($n = 33$)	Univariate tests			
Perceived pain intensity	Mean (SD)	Mean (SD)	F	p	n^2p	β-1
Baseline	70.0 (0.0)	70.0 (0.0)				
1-back	57.7 (6.5)	37.1 (5.9)	4.5	0.03	0.09	0.55
2-back	54.8 (6.1)	30.0 (5.5)	7.5	0.001	0.14	0.76

Table 4. Estimated marginal means and standard deviations (SD) controlling for PPTs.

CI 2.8 to 14.7), and higher selective attention scores (mean difference: 133.3, 95% CI 100.2 to 166.4) than elderly subjects (Table 2).

Effect of age controlling for sociodemographic and psychological variables

The repeated-measures ANCOVA (the estimated marginal means and standard deviations are shown in Table 3) revealed a main effect of the distraction task (Wilk's $\lambda = 0.55$, F [2,49] = 19.7, $p < 0.001$, $n^2p = 0.44$, β-1 = 0.99). Post hoc analyses indicated that perceived pain intensity scores were lower in both 1-back (mean difference: − 24.8, 95% CI − 37.7 to − 11.9, $p < 0.001$) and 2-back (mean difference: − 29.6, 95% CI − 41.4 to − 17.9, $p < 0.001$) tasks compared to baseline. No significant differences in perceived pain intensity scores were found between 1-back and 2-back tasks (mean difference: 4.8, 95% CI − 2.1 to 11.7, $p = 0.279$).

There was no significant interaction between the distraction task and age group after controlling for sociodemographic (sex, marital status, educational level, employment status) or psychological (anxiety and pain anxiety) variables (Wilk's $\lambda = 0.99$, F [2,49] = 0.08, $p = 0.92$, $n^2p = 0.00$, β-1 = 0.06).

Effect of age on perceived pain intensity controlling for PPTs

The repeated-measures ANCOVA (the estimated marginal means and standard deviations are shown in Table 4) showed a main effect of the distraction task (Wilk's $\lambda = 0.78$, F [2,49] = 19.7, $p = 0.005$, $n^2p = 0.21$, β-1 = 0.86). Pairwise comparisons indicated that perceived pain intensity scores were lower during 1-back (mean difference: − 22.5, 95% CI − 32.4 to − 12.7, $p < 0.001$) and 2-back (mean difference: − 27.5, 95% CI − 36.7 to − 18.3, $p < 0.001$) tasks than as baseline. Nevertheless, no significant differences in perceived pain intensity scores were found between both the 1-back and 2-back tasks (mean difference: 4.9, 95% CI − 0.2 to 10.1, $p = 0.06$).

The analysis revealed a significant interaction between the distraction task and age group after controlling PPTs at the neck, hand and leg (Wilk's $\lambda = 0.85$, F [2,49] = 3.7, $p = 0.01$, $n^2p = 0.14$, β-1 = 0.66). Post hoc analyses showed that younger adults (lower PPTs) reported higher perceived pain intensity scores during both the 1-back (mean difference: 20.6, 95% CI 1.1 to 40.0, $p = 0.03$) and 2-back tasks (mean difference: 24.7, 95% CI 6.6 to 42.9, $p < 0.001$) in comparison to elderly (with higher PPTs) adults.

Effects of age and working memory on perceived pain intensity

The repeated-measures ANOVA (the estimated marginal means and standard deviations for perceived experimentally induced pain intensity during 1-back and 2-back tasks are shown in Tables 5 and 6, respectively) showed a main effect of the distraction task (Wilk's $\lambda = 0.48$, F [2,51] = 27.0, $p < 0.001$, $n^2p = 0.51$, β-1 = 0.99). Pairwise comparisons indicated that perceived pain intensity scores were lower during the 1-back (mean difference: − 26.4, 95% CI − 37.4 to − 15.3, $p < 0.001$) and 2-back (mean difference: − 30.9, 95% CI − 41.3 to − 20.5, $p < 0.001$) tasks than as baseline. Further, no significant differences in perceived pain intensity scores between 1-back and 2-back tasks were seen (mean difference: − 4.5, 95% CI − 10.3 to 1.2, $p = 0.17$).

No significant interaction between the distraction task and age group after controlling for the level of function in working memory was found (Wilk's $\lambda = 0.96$, F [2, 51] = 0.81, $p = 0.44$, $n^2p = 0.03$, β-1 = 0.18). Thus, there was not a significant interaction effect between distraction task, the age group and the level of functioning in working memory (Wilk's $\lambda = 0.92$, F [4,102] = 0.95, $p = 0.43$, $n^2p = 0.03$, β-1 = 0.29), after controlling for the D2_TOT raw scores as covariate.

Effects of age and mental Inhibition on perceived pain intensity

The repeated-measures ANOVA (Tables 5 and 6) showed a main effect of the distraction task (Wilk's $\lambda = 0.72$, F [2,51] = 9.5 p = < 0.001, $n^2p = 0.27$, β-1 = 0.97). Pairwise comparisons indicated that perceived pain intensity

Auditory working memory							
	Low (n = 14)	Medium (n = 32)	High (n = 13)	Univariate tests			
Group	Mean (SD)	Mean (SD)	Mean (SD)	F	p	n^2_p	β-1
Young adults	50.8 (10.3)	64.2 (8.8)	38.6 (16.8)	1.29	0.28	0.04	0.26
Elderly adults	33.3 (15.5)	42.3 (7.5)	32.2 (9.0)	0.48	0.61	0.01	0.12
Attentional and inhibitory control							
	Low (n = 9)	Medium (n = 40)	High (n = 10)	Univariate tests			
Group	Mean (SD)	Mean (SD)	Mean (SD)	F	p	n^2_p	β-1
Young adults	46.6 (14.0)	64.8 (9.9)	56.3 (18.9)	0.72	0.49	0.02	0.16
Elderly adults	18.4 (19.6)	38.2 (8.7)	36.5 (15.9)	0.82	0.44	0.03	0.18
Response inhibition							
	Low (n = 12)	Medium (n = 44)	High (n = 3)	Univariate tests			
Group	Mean (SD)	Mean (SD)	Mean (SD)	F	p	n^2_p	β-1
Young adults	50.8 (9.3)	65.7 (9.0)	22.44 (27.9)	1.65	0.20	0.06	0.33
Elderly adults	49.6 (28.5)	37.3 (6.3)	23.9 (19.7)	0.31	0.73	0.01	0.09
Mental flexibility							
	Low (n = 8)	Medium (n = 47)	High (n = 4)	Univariate tests			
Group	Mean (SD)	Mean (SD)	Mean (SD)	F	p	n^2_p	β-1
Young adults	47.3 (13.3)	59.2 (7.5)	0 (0.0)*	0.78	0.38	0.01	0.14
Elderly adults	36.4 (20.9)	37.6 (6.6)	40.2 (14.3)	0.01	0.98	0.00	0.05

Table 5. Estimated marginal means and standard deviations (SD) for perceived pain intensity during the 1-back task. n number of subjects; *no subjects were found for this condition.

Auditory working memory							
	Low (n = 14)	Medium (n = 32)	High (n = 13)	Univariate tests			
Group	Mean (SD)	Mean (SD)	Mean (SD)	F	p	n^2_p	β-1
Young adults	44.4 (9.6)	59.7 (8.2)	27.3 (15.7)	2.22	0.11	0.07	0.43
Elderly adults	32.6 (14.5)	35.8 (7.1)	34.0 (8.4)	0.03	0.96	0.00	0.05
Attentional and inhibitory control							
	Low (n = 9)	Medium (n = 40)	High (n = 10)	Univariate tests			
Group	Mean (SD)	Mean (SD)	Mean (SD)	F	p	n^2_p	β-1
Young adults	34.5 (13.1)	61.3 (9.3)	61.3 (17.6)	1.38	0.26	0.05	0.28
Elderly adults	10.0 (18.3)	31.9 (8.1)	37.6 (14.9)	1.04	0.36	0.03	0.22
Response inhibition							
	Low (n = 12)	Medium (n = 44)	High (n = 3)	Univariate tests			
Group	Mean (SD)	Mean (SD)	Mean (SD)	F	p	n^2_p	β-1
Young adults	42.1 (8.8)	60.6 (8.5)	22.8 (26.2)	2.09	0.13	0.07	0.41
Elderly adults	47.1 (26.7)	34.2 (5.9)	23.0 (18.5)	0.29	0.74	0.01	0.09
Mental flexibility							
	Low (n = 8)	Medium (n = 47)	High (n = 4)	Univariate tests			
Group	Mean (SD)	Mean (SD)	Mean (SD)	F	p	n^2_p	β-1
Young adults	26.8 (12.0)	55.7 (6.8)	0 (0.0)*	5.63	0.02	0.09	0.64
Elderly adults	30.1 (18.9)	36.0 (6.0)	36.8 (12.9)	0.05	0.95	0.00	0.05

Table 6. Estimated marginal means and standard deviations (SD) for perceived pain intensity during the 2-back task. n number of subjects; *no subjects were found for this condition.

scores were lower in the 1-back task (mean difference: −28.3, 95% CI −47.2 to −9.4, $p = 0.002$) and 2-back task (mean difference: −31.6, 95% CI −49.3 to −13.8, $p < 0.001$) when compared with baseline. No significant differences in perceived pain intensity scores were found between 1-back and 2-back (mean difference: −3.2, 95% CI −13.4 to 6.8, $p = 0.99$) tasks.

There was no significant interaction between the distraction task and age group after controlling for the level of functioning in mental inhibition (Wilk's λ = 0.99, F [2,51] = 0.15, $p = 0.85$, $n^2p = 0.00$, β-1 = 0.07). Further, there is no significant interaction between distraction task, age group, and the level of functioning in mental inhibition (Wilk's λ = 0.96, F [4,102] = 0.44, $p = 0.78$, $n^2p = 0.01$, β-1 = 0.14) after controlling for the D2_TOT raw scores as covariate.

Effects of age and cognitive flexibility on perceived pain intensity

The analysis revealed a main effect of the distraction task (Wilk's $\lambda = 0.54$, F [2,51] = 21.9, $p < 0.001$, $n^2p = 0.45$, β-1 = 0.99). Pairwise comparisons indicated that perceived pain intensity scores were lower after 1-back (mean difference: − 25.8, 95% CI − 39.9 to − 11.6, $p < 0.001$) and 2-back (mean difference: − 32.8, 95% CI − 45.6 to − 20.0 $p < 0.001$) task than at baseline. In addition, perceived pain intensity scores were lower during the 2-back task (mean difference: − 7.0, 95% CI − 14.0 to − 0.12, $p = 0.04$) than during the 1-back task (Tables 5 and 6).

The analysis did not reveal a significant interaction between the distraction task and age group after controlling for the level of functioning in cognitive flexibility (Wilk's $\lambda = 0.97$, F [2,51] = 0.71, $p = 0.49$, $n^2p = 0.02$, β-1 = 0.16). Again, no significant interaction between distraction task, age group, and the level of functioning in cognitive flexibility (Wilk's $\lambda = 0.96$, F [2,51] = 0.93, $p = 0.40$, $n^2p = 0.03$, β-1 = 0.20), after controlling for the D2_TOT raw scores as covariate was observed.

Effects of age and attention level on perceived pain intensity

The repeated-measures analyses (Tables 5 and 6) showed a main effect of the distraction task (Wilk's $\lambda = 0.53$, F [2,51] = 22.6, p = < 0.001, $n^2p = 0.47$, β-1 = 0.99). Pairwise comparisons indicated that perceived pain intensity scores were lower during 1-back (mean difference: − 26.4, 95% CI − 38.4 to − 14.5, $p < 0.001$) and 2-back (mean difference: − 30.5, 95% CI − 41.6 to − 19.3, $p < 0.001$) tasks than at baseline. Thus, no significant differences in perceived pain intensity scores between 1-back and 2-back tasks were found (mean difference: − 4.0, 95% CI − 10.2 to 2.2, $p = 0.35$).

No significant interaction between the distraction task and age group after controlling the attention level was identified (Wilk's $\lambda = 0.94$, F [2,51] = 1.6, $p = 0.20$, $n^2p = 0.06$, β-1 = 0.32). Likewise, no significant interaction between the distraction task, age group, and attention level (Wilk's $\lambda = 0.99$, F [4,102] = 0.12, $p = 0.97$, $n^2p = 0.00$, β-1 = 0.07), after controlling for the D2_TOT raw scores as covariate was observed.

Discussion

The current study found the decrease in experimentally induced pain observed after the application of a distraction task was not related to age, psychological, or neurocognitive variables in a sample of asymptomatic pain-free individuals. On the contrary, a significant effect of pressure pain sensitivity was observed where elderly adults who showed higher PPTs (i.e., lower pressure pain sensitivity) reported lower pain intensity scores during the distraction tasks than younger adults who showed lower PPTs.

In the current study, we investigated the effect of two visual distraction tasks (n-back) on experimental-induced acute pain considering aging and found that both tasks reduced the intensity of pain levels in both young and elderly adults. Our results are in agreement with previous studies showing that visual distraction tasks induce hypoalgesia in acute pain settings[56,57]. However, it should be recognized that previous studies nor the current one included a control group who did not receive a distraction task. Accordingly, we do not know the variability in reported pain perception over time without the application of a distraction task. Nevertheless, it is important to note that our study was not focussed on the hypoalgesic effect of a distraction task against a control, if not the effect of age. In fact, previous studies did not consider the effect of age in their designs. Thus, considering aging, heterogeneous data have been published. Previous studies observed that hypoalgesia induced by a distraction task was lower in old adults than in young adults[58,59]. In contrast, consistent with the findings of the current study, Lithfous et al. did not find differences in hypoalgesia between older and younger adults during distraction tasks[60]. Similarly, other studies have also shown that older participants experience pain relief through distraction similarly to younger participants. However, these studies have also suggested that aging may amplify the emotional aspects of pain perception. Therefore, when considering hypoalgesia in the context of aging, it is important to account for psychological, biological, and neurocognitive factors[61].

Distraction task, hypoalgesia, and psychological/emotional aspects

It seems that psychological/emotional aspects vary across the lifespan; however, data about differences in anxiety and depressive levels between young and elderly people is conflicting due to heterogeneous eligibility criteria, sampling methods, and measurement tools[62]. We observed that our sample of young adults exhibited higher anxiety, but similar depressive levels compared to elderly adults. Our results agree with a review of reviews reporting that younger age was associated with higher levels of anxiety[63] and with current data showing that depression is not commonly seen in elderly adults[64]. In fact, a recent study using machine learning language has reported that middle-aged adults show better mental health than younger adults by analyzing the semantic meaning of emotional aspects[65]. This study also identified that young adults focused on anxiety levels to a greater extent than middle-aged and elderly adults, which would also support the higher anxiety levels observed in our sample of young adults. Nevertheless, neither anxiety nor depressive levels influenced the hypoalgesia induced by the distraction tasks in either age group in the current study.

Distraction task, hypoalgesia, and pain processing

An interesting finding of the current study was the interaction between the distraction task, age, and pressure pain sensitivity. We observed that hypoalgesia induced by distraction tasks was more pronounced in elderly adults compared to younger adults, as indicated by higher pain pressure thresholds (PPTs), reflecting lower pain sensitivity in older adults. Contrary to our findings, some studies have reported that pain modulation induced by a simple cognitive task, such as tone detection, may actually worsen pain in older participants[59,66]. Zhou et al.[59,66] suggested that this lack of pain reduction through distraction might be attributed to reduced functioning of frontal networks. Some studies also proposed that distraction tasks may exacerbate pain in older adults when they deplete cognitive resources that are already strained by pain. For instance, Zhou et al.[59] found that, although pain intensity was high, the cognitive load of their distraction task was low, leading to reduced hypoalgesic effect in younger subjects and increased perceived pain during distraction in older adults. It is well-established that the effectiveness of a distraction task can diminish with higher pain intensity or chronicity[67]. In our study, the pain stimuli were of moderate intensity, and the high-distraction task, while not overly challenging, required sustained attention, leading to high involvement in the task. In line with our findings, some research has also shown that working memory distraction tasks (e.g., 1- and 2-back tasks) reduce the perceived intensity of thermal stimuli, regardless of whether these stimuli are nociceptive, suggesting that distraction-induced hypoalgesia persists with aging[60].

Data on pain sensitivity and aging are conflicting. Lautenbacher et al. found that pain thresholds increased with age, indicating lower pain hyperalgesia, whereas pain tolerance thresholds did not significantly differ between younger and older groups[68]. In contrast, a meta-analysis by El Tumi et al. indicated that PPTs were lower in older adults compared to younger adults, while no differences were observed in contact heat pain thresholds between the two age groups, suggesting that older adults may be more sensitive to mechanically-evoked pain but not to heat-evoked pain compared to younger adults[69]. In the present study, we observed lower PPTs in younger compared to older adults, consistent with Yezierski et al.[70] but contrary to a recent study by Zhi et al.[71], which found no correlation between PPTs and age. Discrepancies may be attributed to variations in study design, populations, or types of painful stimuli.

Evidence supports the presence of an altered pain processing in elderly adults associated with an imbalance between excitatory and inhibitory pain pathways[61]. Pain processing is highly complex, involving the transduction and transmission of mechanical, chemical, or thermal noxious stimuli from peripheral receptors to the brain. Numerous anatomical structures participate in this process, including myelinated and unmyelinated fibers, dorsal root ganglia, the spinal cord, and supraspinal structures[72]. Age-associated changes can affect any of these stations, potentially leading to altered pain processing. A recent systematic review and meta-analysis, which included 40 studies involving 6955 patients over 60 years of age, found that age-related changes were more evident when heat stimulation was used as a stressor, rather than with pressure or electrical current[68]. Heat stimuli, which are particularly effective in demonstrating an age-related decline in pain sensitivity, are mediated by C-fibers located primarily in superficial tissues. In contrast, pressure pain is mediated by deep tissue nociceptors, while electrical current directly activates Aδ-fibers, bypassing receptor mechanisms[68]. Earlier narrative reviews have suggested a trend toward increased pain thresholds and decreased tolerance thresholds with age; however, these findings have not been confirmed[7,68,73]. On the other hand, some other studies proposed that the balance between excitatory and inhibitory pain mechanisms is dampened with age, but this process seems to be faster for inhibition[7]. Thus, the prevalence of chronic pain conditions increases with age[74,75] and has been associated with a decline in endogenous pain inhibition associated with aging[76] rather than an increase in excitatory mechanisms. In fact, brain studies reveal reduced functional connectivity between key nodes of descending inhibitory pain pathways[5] and lower connections associated with conditioned pain modulation, e.g., periaqueductal gray substance, in old adults[77]. The presence of higher PPTs in our sample of elderly adults means lower hyperalgesia to pressure pain, which agrees with current theories about normal excitatory pain mechanisms in old adults. Thus, the presence of normal excitatory pain pathways in old adults was the only factor associated with hypoalgesia induced by the distraction tasks in the current study.

Distraction task, hypoalgesia, and neurocognitive tests

We did not find an association between different executive functions (cognitive flexibility, mental inhibition, working memory, and attention) and hypoalgesia induced by distraction tasks in either young or elderly adults. Our results are in line with a systematic review summarizing that the effect of executive functioning on responsiveness to experimental pain is weak and that only 20% of published studies found only small correlations[78].

Few studies have investigated the effect of different neurocognitive tests by age groups[58,59,79]. It is important to consider that we found that elderly adults showed better scores in mental inhibition, cognitive flexibility, and working memory and lower scores in attention levels than younger adults. This finding may potentially explain the lack of differences in hypoalgesia with distraction tasks between young and elderly adults in our study since the preservation of executive functions with aging may have beneficial effects on the hypoalgesia of distraction from pain[79].

Executive functions typically show prolonged development into early adulthood and decline with aging, coinciding with structural and functional changes in the PFC[80–82]. In fact, older adults tend to experience a significant decline in various executive functions, e.g., working memory[83], inhibition[84], or planning[85]. Thus, although age effects on executive functions are generally considered robust and can be linked to structural changes in the frontal lobes[86], which exhibit diverse developmental trajectories across the lifespan[13,87]. Others have suggested an inverted U-shaped curve of executive functions across the lifespan[88–90].

In line with the results obtained in our study, evidence also shows that older adults may exhibit the same or even greater capacity in executive functions than young adults, challenging the traditional notion of an inevitable decline in these skills with age. It has been observed that older adults were more effective in selecting strategies to solve interpersonal problems than younger people, suggesting an advantage in managing conflicts based on accumulated life experience[91]. This finding is consistent with the idea that practical wisdom and emotional skills improve with age, which might compensate for possible deficits in other aspects of executive functions.

Nagel et al.[92] observed that older adults were able to maintain similar performance levels as young adults in memory tasks and working under conditions of low demand, suggesting that elderly people can potentially manage their executive resources in some situations[92]. These findings were explained by Suzuki et al.[93], who identified that, in advanced ages, cortical over-recruitment occurs (higher amounts of resources directed to accomplish the task), where the brain may play a compensatory role in mediating working memory performance. In other words, although the brain of elderly adults may show signs of decline in certain executive functions, increased activity in cortical areas could help to maintain performance on working memory tasks, hence compensating for deficiencies associated with aging[93].

From a psycho-emotional viewpoint, Scheibe and Blanchard-Fields (2009) found that elderly adults experience fewer cognitive performance costs when regulating their emotions compared to younger adults[94]. This advantage in emotional regulation could potentially improve their performance during executive tasks requiring emotional control, such as mental inhibition of a painful stimulus (as we have conducted in our research), showing that in specific contexts, elderly adults may have a greater advantage than younger adults.

Therefore, although there would be a decline in certain executive functions with increasing age, evidence suggests that older adults can outperform younger adults in specific contexts where experience, emotional regulation, and adaptive strategies play a crucial role. Current and previous findings challenge traditional perspectives on cognitive aging and highlight the relevance of a more nuanced approach when studying executive functions across the lifespan.

Conclusion

This study found that a distraction task (1-back and 2-back) reduces the perceived intensity of experimental-induced pain, and this effect was not related to age, psychological, or neurocognitive variables in asymptomatic pain-free subjects. A significant effect of pressure pain sensitivity was identified where elderly adults who showed lower pressure pain hyperalgesia reported lower pain intensity scores during the distraction tasks than younger adults who exhibited higher hyperalgesia to pressure pain. Future studies in different populations controlled by age should be conducted to identify the hypoalgesic response of the distraction tasks used in this study.

Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Declarations

Competing interests

The authors declare no competing interests.

Additional information

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