Randomized Study

Exercise- and Stress-Induced Hypoalgesia in Musicians with and without Shoulder Pain: A Randomized Controlled Crossover Study

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Background: Professional and pre-professional musicians are characterized by physical and psychological demands inherent to their musical activity, and therefore at risk for developing performance related musculoskeletal pain. Physical and psychological demands are known to influence human pain modulation.

Objectives: In this study we compared the influence of a physically and emotionally stressful task on pain thresholds in musicians with and without shoulder pain.

Study Design: A single-blinded randomized and controlled crossover study design was used to compare the effects of a physical versus emotional testing procedure on pressure pain thresholds (PPTs) in musicians with and without shoulder pain.

Setting: All data were obtained in the field (e.g., at the physiotherapy accommodation in the Royal Conservatory).

Methods: During the physical testing procedure, the subjects performed an isometric exercise of the glenohumeral external rotators. The emotional task comprised watching "unpleasant" images selected from the International Affective Picture System. The outcome was the assessment of change in PPTs before and after the physical and emotional task.

Results: Our results indicate similar effects of both protocols in either group, i.e., musicians with and without shoulder pain ($P > 0.05$). All musicians showed elevated PPTs at local and remote areas after isometric exercise ($P < 0.05$). The emotional stress task increased PPTs at remote areas only ($P < 0.05$).

Limitations: Despite the small sample size of musicians without shoulder pain, a power of 78.5% was achieved to detect the necessary effect size of Cohen's d = 1. Furthermore, comparing these results with those of non-musicians (both healthy subjects and patients with shoulder pain) might reveal information regarding the specific adaptations. Finally a high variability was observed in shoulder disability (i.e., SDQ-scores) as typically seen in a population with shoulder pain.

Conclusions: In musicians with and without regional shoulder pain, no significant differences were found with respect to pain modulation during a physically and an emotionally stressful task. Both interventions adequately activated central and widespread pain inhibitory mechanisms in both groups.

Key words: Pressure pain threshold, PPT, exercise induced hypoalgesia, exercise induced analgesia, stress induced hypoalgesia, shoulder pain, musicians, regional pain**:**

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Professional and pre-professional (i.e., enrolled full-time in a Master's degree program) musicians are at risk of developing performance-related musculoskeletal pain. The point prevalence of pain and other musculoskeletal disorders is substantially higher than in a general population (1) and values up to 87% have been reported (2-4). Especially musicians playing in an elevated arm position, such as violinists, suffer from shoulder pain (5).

Shoulder pain in musicians may be similar to symptoms experienced by athletes using overhead positions (6-9). Incorrect posture, faulty technique, motor control deficits, sensorimotor incongruence, excessive force, overuse, and insufficient rest have all been proposed as contributing factors to the development of pain and injuries in both athletes (7,8,10,11) and musicians (12,13).

Musicians experience high physical and psychological demands inherent to their specific musical activity (2,4,14). These demands are known to influence human endogenous pain modulation, both in healthy people and in patients with pain (15-19). Pain perception during and after exercise is determined by several factors such as the type, intensity, and duration of exercise (15,20). Generalized exercise-induced hypoalgesia is observed in healthy people following local muscular contractions (15,20-23) and is contrasting to the generalized hyperalgesia observed in patients suffering from chronic widespread pain conditions characterized by the presence of central sensitization (15,24). The latter indicates a dysfunctional response to exercise, suggesting maladaptive pain modulation (15,23-25). In patients with chronic musculoskeletal pain, distinct types of exercise may cause an exacerbation of pain (23,24). In addition, emotion and cognition may further modulate the perception of pain (16-19). In healthy people, for example, fear may decrease pain perception (hereafter referred to as stress-induced hypoalgesia), while anxiety may increase the sensation of pain (19).

Given the high physical and emotional demands musicians experience on a daily basis, it is warranted to study their physiological response to physical and emotional stress. With respect to the effects of various types of stress on the pain modulation system, studies in musicians are essentially lacking. Given the high prevalence of pain disorders among musicians, this is a severe shortcoming in the literature.

Therefore, the present study examines the effect of the physical and psychological load on mechanical pain perception in string players with and without playing-related shoulder pain. We hypothesized that musicians with playing-related shoulder pain would react differently compared with those without pain when exposed to both tasks.

Methods

Design

A single-blinded observer randomized and controlled crossover study design was used to compare the effect of a physical and an emotional stressor on pain thresholds in musicians with and without shoulder pain. All participants (i.e., the musicians with and without shoulder pain) were contacted and informed about the study by a researcher who was not involved in the testing of the participants. If the musicians agreed to participate, they were scheduled by this researcher, so that the assessors involved in the tests remained blinded to the participants' condition. The study was approved by the local ethics committee. Written informed consent was obtained from all participants prior to their inclusion in the study.

Participants

Professional and pre-professional string (violin, viola, cello, and double bass) and guitar (electric and acoustic) players of the Royal Conservatory and of a Royal Philharmonic Orchestra were screened for eligibility. Playing-related shoulder pain was defined as any physical complaint or manifestation recalled as having been present during the previous month and having lasted for a day or longer, and resulting from performance or training, irrespective of the need for medical attention or time loss from playing an instrument (26). Musicians suffering from playing related shoulder pain for a period of at least 2 months were included in the patient group. Severity of the shoulder pain was registered using the Shoulder Disability Questionnaire (SDQ) and Visual Analogue Scales (VAS). To be included as a patient with shoulder pain, a participant had to report a minimal pain level of 1/10 at rest and 3/10 while playing their instrument at the initial contact with the researchers (26). Musicians were included in the control group if they were pain free (i.e., VAS 0/10) at the initial contact and did not perceive shoulder pain in the previous month. Participants were excluded if they suffered from systemic diseases or comorbidities or if their knowledge of the Dutch or English language was insufficient to complete the questionnaires. Using a pressure algometer (Somedic Sales AB, Hörby, Sweden) with a probe area of 1 cm^2, a previous study compared pain modulatory effects of exercise between (shoulder) pain patients and healthy controls and found a mean between group difference of 100 kPa +/- 100, resulting in a Cohen's d value of 1 (23). Assuming a similar effect size, power calculations showed that a sample size of 17 individuals in each group would be sufficient to reach a power of 80% at a significance level of 0.05.

Procedure

A researcher not involved in the testing provided verbal and written information prior to the study. Volunteers willing to participate were asked to read the information leaflet carefully and to sign the informed consent form. Inclusion criteria were checked by the researcher not involved in the assessment of the participants. As clarified in Fig. 1 all participants were randomly allocated to one of 2 protocols (physical vs emotional). This procedure was executed by the researcher not involved in the assessment using simple randomization (manual lottery). Three to 7 days later, participants were crossed over so that each musician performed both protocols. All patients were asked to stop medication use 24 hours prior to study participation and to avoid alcohol, caffeine, and nicotine on the day of study participation.

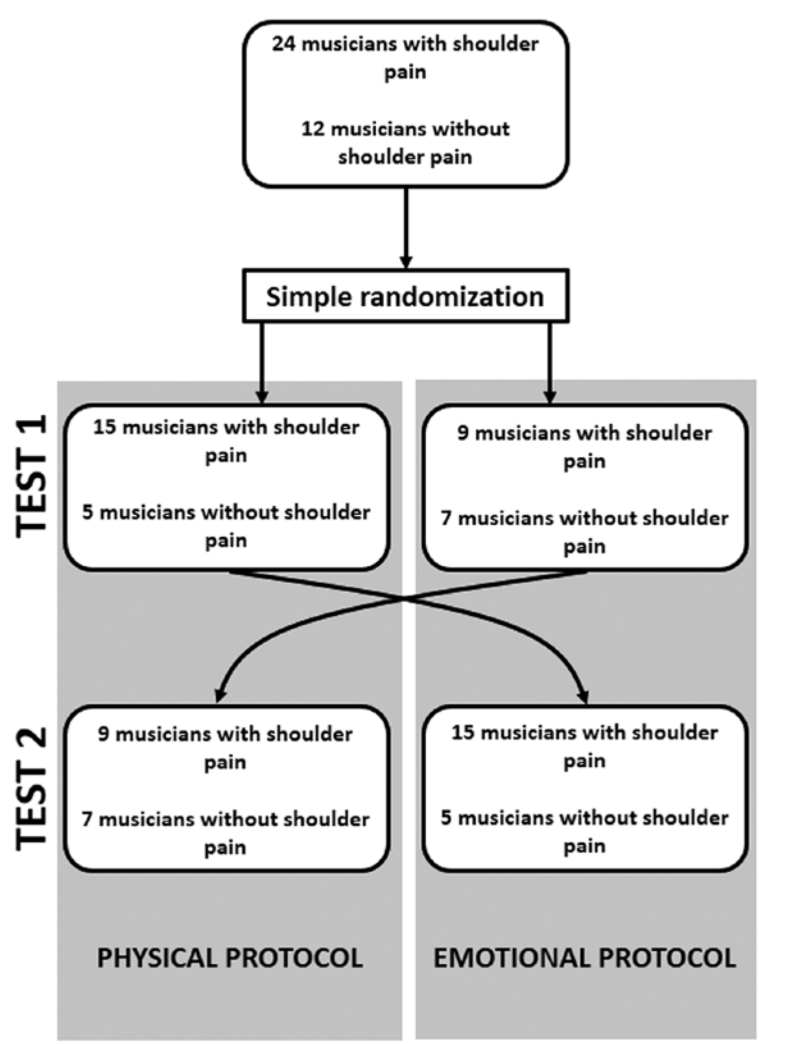


Fig. 1. *Flow chart.*

Outcome Measures

Pressure pain thresholds (PPTs) at several body regions were assessed prior to and following the respective tasks. PPTs were measured bilaterally at the muscle belly of infraspinatus, quadriceps femoris, and tibialis anterior using an analogue pressure algometer (Wagner Instruments, Greenwich, USA) with a probe area of 1 cm^2. The infraspinatus was marked 4.5 cm inferior of the middle of the scapular spine with the participant in the prone position and the arm at 90° abduction. For the quadriceps femoris and tibialis anterior, the participant was seated with hips and knees flexed 90°. The quadriceps femoris was marked at mid distance between the apex patella and spina iliaca anterior superior. For the tibialis anterior, the mid distance between the malleolus lateralis and condylus lateralis tibiae was marked. Force was gradually increased at a rate of 1 kg/s (27). PPT was defined as the point at which the pressure sensation turned to pain (28). The threshold was determined as the mean of the 2 last values out of 3 consecutive (10 seconds in between) measurements, since this procedure has found to be reliable in healthy volunteers. Prior to the study, the inter-tester reliability of the pressure algometry assessment was examined at all 3 locations in a comparable population consisting of 10 participants with and without shoulder pain. Intraclass correlation coefficients of 0.80, 0.83, and 0.98 were obtained for the pressure algometry assessment in the infraspinatus, tibialis anterior, and quadriceps femoris, respectively.

All participants were asked to complete the Dutch or English version of the Short Form 36 Health Status Survey (SF-36), the Pain Vigilance and Awareness Questionnaire (PVAQ), and the Pain Catastrophizing Scale (PCS). In addition, patients answered the Shoulder Disability Questionnaire (SDQ). The clinimetric properties of these questionnaires have been established in relevant populations (29-34). Demographic characteristics, playing-related issues, and the presence of musculoskeletal (pain) symptoms were collected using a self-administered questionnaire.

Physical Protocol

The physical task was based on earlier published protocols (22,23). The maximal voluntary contraction (MVC) of the glenohumeral external rotators was measured using a hand held dynamometer (Fabrication Enterprises, New York). The participant was seated upright on a 2-part bench, adjusted to the participant's height, with the arm positioned at 45° shoulder abduction, 90° elbow flexion, and the forearm in a neutral rotation position. In order to guarantee blinding, the researcher not involved in the clinical assessment prepared the score sheets by specifying which side should be tested. This researcher indicated in the score sheet which side should be tested. In patients the most painful side (referred to as the ipsilateral side) was tested. Healthy participants were randomly matched to obtain parallelism in both tested groups. Participants performed 3 MVCs lasting 5 seconds. After assessment of the MVCs, participants were instructed to rest in order to avoid local muscle fatigue. During this resting period, participants were asked to complete the questionnaires.

For the physical task, all participants performed an isometric contraction (20 – 25% of MVC) of the glenohumeral external rotators until exhaustion or for a maximum of 5 minutes in the same test position. Before and after the task, ratings of perceived exertion were measured using a 6 – 20 points Borg-scale. This scale has been shown to be a valid measure for exercise intensity (35).

Emotional Protocol

Visual stimuli were presented to the participants to trigger emotional responses. Thirty-two "unpleasant" images, that are known to have the highest arousal value, were selected from the International Affective Picture System, a database of colored photographs to assess effects on attention and emotion (36). This database is widely used in neuroscience studies as it allows systematic selection of images with a specific emotional content (37-43). Participants practiced with 2 neutral images to get familiarized with the task. After the practice session, the 32 previously selected and unpleasant images were presented in random order. The images were displayed on a 19-inch (48.3cm) computer screen in a dimly lit room. The screen was placed 1 meter in front of the viewer, resulting in an image presentation with a visual angle of 20°. Each image was presented for a 6 second viewing interval, followed by a 12 second blank screen interval.

Statistical Analysis

One-sample t-tests were used to analyze whether the effects of the 2 protocols, within each of the 2 groups, were significantly different from zero. A paired t-tests was used to test for differences in effects between the 2 protocols, within each group. To test whether the effect of the 2 protocols was different between the 2 groups, linear mixed model analysis was performed. Since each individual was tested twice, adjustment for dependence between observations within the same individual was necessary. This was done by including additional terms ("random effects") to account for the fact that each individual was present twice in the dataset. The real terms of interest ("fixed effects") were then tested for significance. For all outcome variables, association analysis was performed using stepwise backward regression starting from a mixed model with order, protocol, and group as fixed effects, plus all pairwise interaction terms.

Results

Participants included 24 string players with shoulder pain and 12 pain-free musicians. Group demographics are presented in Table 1.

The PPTs, both at the ipsilateral and the contralateral shoulder, significantly increased in all musicians after performing a unilateral rotation exercise of the ipsilateral shoulder (Table 2, physical task). The PPTs increased in all musicians at remote places (c.q., quadriceps femoris and tibialis anterior) as well, but a significant increase was only seen in 2 out of 4 measurements in the musicians with shoulder pain and in 3 out of 4 measurements in pain-free musicians. After the emotional stress task, all musicians significantly increased their PPTs at the lower limbs ($P < 0.05$) but not at the

Table 1. *Demographic characteristics*.

Demographics	Musicians with pain (n = 24)	Pain-Free Musicians (n = 12)	*P*-value
Age (y) ± SD	26.13 ± 12.48	24.83 ± 10.66	.76
Gender (W/M)	14/10	6/6	/
SDQ (%) ± SD	25.23 ± 22.18	NA	/
Pain Duration (months) ± SD	24.2 ± 25.9	NA	/
PVAQ ± SD	41.38 ± 8.08	38.00 ± 15.94	.40
PCS ± SD	13.38 ± 6.99	12.50 ± 9.32	.75
SF-36 ± SD	56.17 ± 9.61	67.33 ± 5.00	.00
Professionalism (PP/P)	20 / 4	10 / 2	/
Years playing instrument ± SD	15.3 ± 10.7	18.3 ± 10.9	.43
Hours playing / wk ± SD	31.1 ± 8.1	35.7 ± 8.2	.19
MVC (kg) ± SD	12.93 ± 4.20	13.56 ± 3.99	.67
RPE (median [IR])	15 (2)	13.5 (2)	.01

Values are mean or as otherwise indicated; SD = standard deviation; y = years of age; W = women; M = men; SDQ = shoulder disability questionnaire; NA = not applicable; PVAQ = pain vigilance and awareness questionnaire; PCS = pain catastrophizing scale; SF-36 = short form 36 Health Status Survey; PP = pre-professional; P = professional; wk = week; MVC = maximal voluntary contraction; RPE = Rating of Perceived Exertion after physical task; IR = interquartile range

Table 2. *Relative changes (%) in Pressure Pain Threshold in musicians with and without shoulder pain during a physical versus an emotional stress task*.

% Change in PPT (SD)	Physical task		Emotional Stress task	
	Pain- Free Musicians (n = 12)	Musicians w/ pain (n = 24)	Pain-Free Musicians (n = 12)	Musicians w/ pain (n = 24)
ipsilateral M. infraspinatus	23.41 (26.42)*	17.48 (29.02)**	1.64 (23.00)	4.15 (16.74)
contralateral M. infraspinatus	14.43 (19.47)*	15.32 (30.64)*	-3.70 (18.53)	5.72 (19.92)
ipsilateral M. quadriceps	1.19 (13.38)	9.42 (18.29)*	12.19 (12.26)**	8.30 (11.24)**
contralateral M. quadriceps	9.44 (9.48)**	5.84 (14.61)	9.77 (13.79)*	7.90 (15.59)*
ipsilateral M. tibialis anterior	12.71 (12.69)**	6.16 (20.85)	5.40 (7.95)*	6.41 (13.33)*
contralateral M. tibialis anterior	11.29 (16.46)*	9.68 (17.52)*	14.87 (38.33)	7.17 (14.70)*

Levels of statistical significance obtained using one-sample t-test: $^{**}P < 0.01$, $^{*}P < 0.05$; n = number of subjects; SD = standard deviation; M = musculus; PPT = Pressure Pain Threshold

Table 3. *Comparison between the physical and emotional stress task.*

% Change in PPT	Pain-Free Musicians (n = 12)			Musicians with shoulder pain (n = 24)		
	Physical task	Emotional stress task	*P*-value	Physical task	Emotional stress task	*P*-value
	Mean (SD)	Mean (SD)		Mean (SD)	Mean (SD)	
ipsilateral M. infraspinatus	23.41 (26.42)	1.64 (23.00)	.071	17.48 (29.02)	4.15 (16.74)	.090
contralateral M. infraspinatus	14.43 (19.47)	-3.70 (18.53)	.009**	15.32 (30.64)	5.72 (19.92)	.180
ipsilateral M. quadriceps	1.19 (13.38)	12.19 (12.26)	.014*	9.42 (18.29)	8.30 (11.24)	.778
contralateral M. quadriceps	9.44 (9.48)	9.77 (13.79)	.944	5.84 (14.61)	7.90 (15.59)	.625
ipsilateral M. tibialis anterior	12.71 (12.69)	5.40 (7.95)	.096	6.16 (20.85)	6.41 (6.41)	.959
contralateral M. tibialis anterior	11.29 (16.46)	14.87 (38.33)	.782	9.68 (17.52)	7.17 (14.70)	.612

Levels of statistical significance obtained using paired t-test: $^{**}P < 0.01$, $^{*}P < 0.05$; SD = standard deviation; n = number of subjects; M = musculus; PPT = Pressure Pain Threshold

shoulder ($P > 0.05$). Overall, the relative changes in PPTs did not differ between musicians with and without shoulder pain ($P > 0.05$).

Finally, no significant differences in change of PPT were observed between the emotional versus physical task in musicians with shoulder pain (Table 3). Those without pain showed a significantly higher increase in PPT at the ipsilateral quadriceps during the emotional protocol and at the contralateral infraspinatus during the physical protocol. Within this crossover design, no significant interaction of order of tasks was found (data not shown).

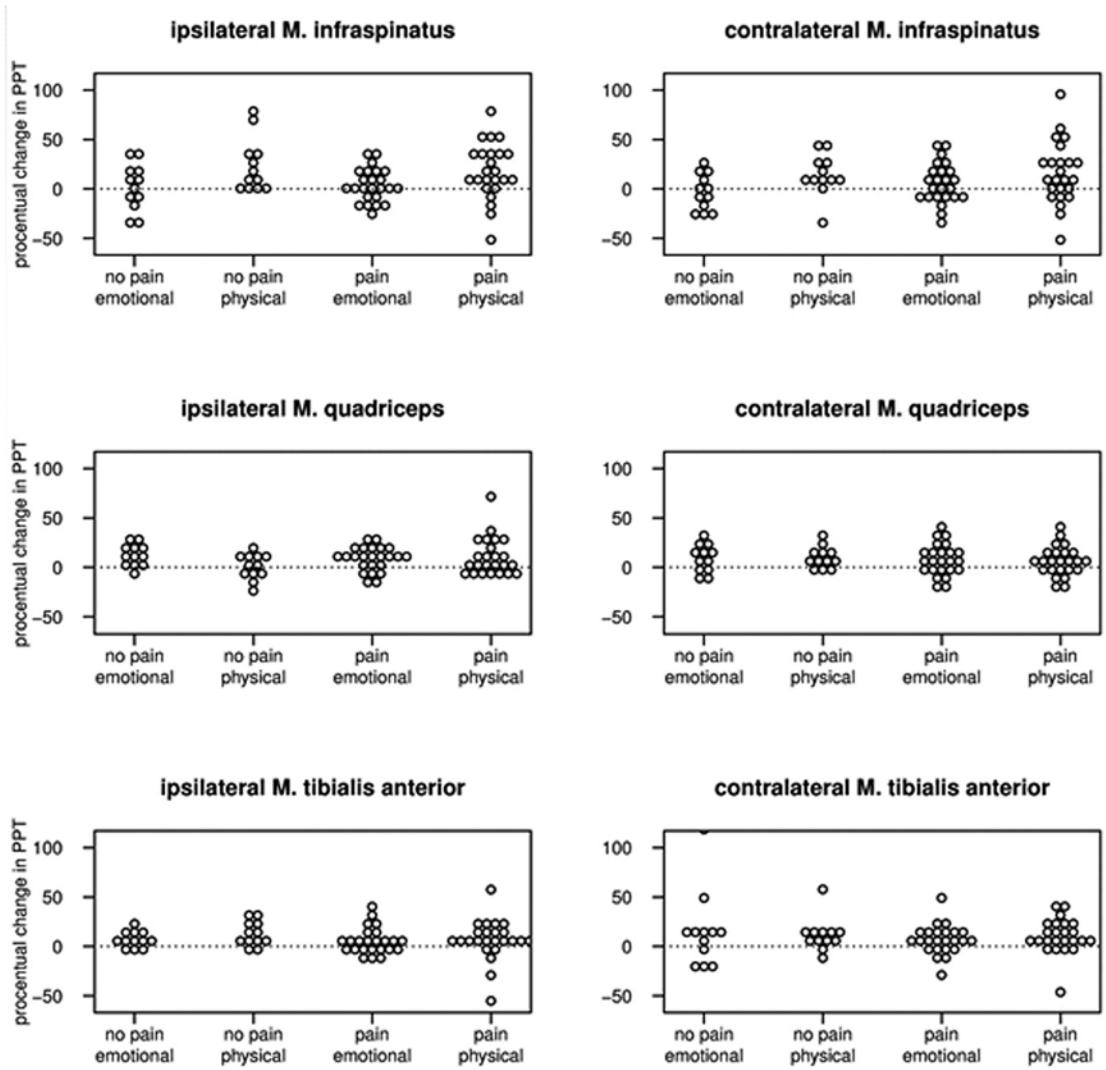
The results are summarized in a bee swarm box-plot (Fig. 2) showing the relative changes in PPTs for all tested regions in all subgroups. Each dot represents the percentage change PPT in one individual, for the 4 combinations of group and protocol. To avoid overplotting, points have been jittered along the X-axis.

Discussion

This study examined the influence of a physically versus an emotionally stressful task on PPTs in musicians with and without playing-related shoulder pain. In both groups, an increase in PPTs was observed in the shoulder regions following the physical task, but not following the emotionally stressful task. Furthermore, significant increases in PPTs were observed at several remote body parts after both tasks, suggesting that brain-orchestrated endogenous analgesia was adequately activated. However, no differences were observed between musicians with and without playing-related shoulder pain.

These results suggest that both exercise- and stress-induced hypoalgesia occur in musicians with and without shoulder pain, but at different locations. With respect to exercise-induced hypoalgesia, our results confirm the findings of hypoalgesic effects of moderate-to-high intensity isometric contraction in healthy individuals (15,21,22,44). Despite the fact that exercise-induced hypoalgesia during and after various types of exercise is well observed and studied in healthy individuals and patients with chronic pain, the exact underlying mechanisms are not fully understood (15,20,21,44,45). One possible explanation might be the activation of the endogenous opioid system with a release of peripheral and central beta-endorphins (15,24). Another potential mechanism involves an interaction between pain modulatory and cardiovascular systems (16,45). Increasing blood pressure by exercise does activate arterial baroreceptors resulting in increased supra-spinal inhibition (45). Furthermore activation of ascending (e.g., activation of muscle afferent A-delta and C-fibers) and descending (e.g., exercise acting as a distraction and altering attention away from the pain stimulus) pain inhibitory pathways can explain this exercise-induced hypoalgesia.

Patients suffering from chronic widespread (e.g., fibromyalgia) or regional/local (e.g., myalgia) musculoskeletal pain are often characterized by a malfunctioning pain processing system featuring exercise-induced hyperalgesia (23,24,46). However, current results do not suggest differences in exercise-induced hypoalgesia between healthy musicians and those with playing-related shoulder pain. First, the rather local area of pain may explain differences between our study and earlier evidence. The majority of the studies reporting dysfunctional endogenous analgesia were performed in patients experiencing widespread pain (25,47). Several authors suggest that patients suffering from a regional pain problem (e.g., trapezius myalgia) experi-



Bee swarm plot of all the results. Each dot represents the percentage change PPT in one individual, for the 4 combinations of group and protocol. To avoid overplotting, points have been jittered along the X-axis. PPT = Pressure Pain Threshold; M. = Musculus; no pain = musicians without pain; pain = musicians with pain; emotional = emotional protocol; physical = physical protocol

Fig. 2. *Bee swarm boxplot overview of all results.*

ence generalized hypoalgesia during and after exercise but only when exercise was applied on a non-painful muscle (15,23,24,48). However, our results show hypoalgesic effects after exercising the painful shoulder. In addition, the duration and course of the symptoms may also be an issue. The shoulder symptoms in the included musicians with pain might be considered as recurrent symptoms, as opposed to the chronic symptoms experienced by patients in other studies.

As mentioned above our results also demonstrate the presence of stress-induced hypoalgesia in both groups. This type of pain modulation can partly be explained by the presence of a physiologic arousal. Fear is for example considered as an immediate alarm reaction to an actual threat, characterized by impulses to escape, which typically results in sympathetic arousal

(19,49). Inhibition of a nociceptive reflex following an alarm state probably occurs in order to take action (19). The stress-induced hypoalgesia demonstrated by the current study is mediated by descending pain-inhibitory circuits (also apparent in exercise-induced hypoalgesia) and can be an indicator of adequate centrally mediated pain control both in musicians with and without pain. This finding is in accordance with earlier studies concluding that the presence of pain in patients does not disrupt the acute effect of experimentally induced stress on pain sensitivity (50).

It is important to differentiate between types of stress and emotion. Rhudy and Meagher (19) showed an adverse reaction on pain thresholds after a state of fear (increase) compared with a lower state of arousal such as anxiety (decrease). In this study, we specifically intended to induce a state of high sympathetic arousal by using pictures from the International Affective Picture System known to have the highest arousal value.

No significant differences were observed when comparing the increase of PPTs during the emotional versus physical task in musicians with pain. Within this group we can therefore conclude that using physical and acute emotional stress equally activates the central and widespread pain inhibitory mechanisms.

Our population only included musicians performing more than 30 hours of musical activity weekly and might therefore not represent the general population. The presented results could possibly be interfered by adaptations as seen in other specific populations. Indeed recent studies confirmed the presence of altered and adapted pain processing in a specific population of healthy endurance athletes (51,52). Further research concerning this topic is needed.

The results of this study should be interpreted in the light of some study limitations. Firstly, a small sample size, more precisely in the population of musicians without pain, makes it difficult to generalize our findings. Our final sample size included 12 pain-free musicians and 24 musicians with pain. It was not possible to extend the group of pain-free musicians recruited in the Royal Conservatoire and Philharmonic Orchestra as they suffered from pain symptoms. This confirms previous results, i.e., that about 80% of the musicians in professional orchestra suffer from playing related musculoskeletal pain (2,3,53,54). However, post hoc power calculations demonstrate that the present study offers 78.5% power to detect the previously reported effect size of a Cohen's d = 1. Secondly, all participants performed both protocols, but the time intervals between the 2 protocols varied between 3 to 7 days. We, however, do not expect differences in the results that can be attributed to this variable time interval. Recent work performed by Walton et al (55) in patients with neck pain concluded that a one-week test-retest reliability is adequately stable over that period. Moreover, we did not include participants with acute shoulder pain assuming they are characterized by a more variable pain perception. Finally, all results were based on relative changes of PPTs. Thirdly, the randomization was performed for the group as a whole, thereby not taking the status of each participant into account. We did not have exactly the same numbers of participants in each group. Post hoc analysis did not however demonstrate a significant interaction of order of tasks. Fourthly, a control group of age-matched non-musicians (healthy participants as well as patients with shoulder pain) would give us the opportunity to gain more insight in the interactions between pain conditions and musical load. However, the use of a crossover design, by which every participant underwent both test protocols, is certainly a major strength of this study, as it partly justifies the low number of included participants. Furthermore we acknowledge the high variability in shoulder disability (i.e., SDQ-scores) as typically seen in a shoulder pain population.

Conclusion

In conclusion, both exercise- and stress-induced hypoalgesia are extremely relevant in musicians as they experience high physical and psychological demands (2,4,14). Our results suggest that in musicians with and without regional pain, brain-orchestrated endogenous analgesia is activated in response to physical and emotional stress. At this moment it is unclear which type of hypoalgesia (exercise- or stress-induced) is of higher importance during musical activity. Further research is necessary to gain more insight.

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