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Exercise - induced Hypoalgesia in Physically Active Men Following Different Exhaustive Cycle-ergometries

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Authors' contributions

This work was carried out in collaboration between all authors. Authors KB and LS planned the study, wrote the protocol, managed the experiments, and searched for literature. Author UH performed the statistical analysis. Author KB wrote the first draft of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Purpose: The study deals with changes in pressure pain thresholds (PPT) after exhaustive exercises. Two different protocols were applied to trained men of different age groups and the magnitude of exercise induced hypoalgesia (EIH) compared in inactive and loaded muscles.
Methods: 30 healthy and physically active males (15 young and 15 old) completed two exhaustive cycle-exercises with an incremental load test (ILT; 25W x min^{-1}) and a constant load test (CLT) performed at 100% of maximal load during ILT. A control test was performed in order to allow for repeated measurement effects. Before, 1 minute, and 4 minutes after exercise PPT was examined from the middle part of the thenar and the quadriceps. In addition, resting and peak values of heart rate and lactic acid concentration ([lac]) were measured.
Results: Repeated measurements did not influence PPT in the young but had a significant effect in the elderly. After adjusting for this baseline drift, EIH did not significantly differ between young and old subjects. While exercise did not change PPT in the inactive thenar, significant increases occurred in the quadriceps. The reduction in pain sensitivity was significantly (p < 0,01) more

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pronounced after the constant load test although exercise duration and the total amount of work was significantly lower. Peak heart rate and peak [lac] were comparable in both tests.
Discussion: The amount of EIH after exhaustive, dynamic exercise does not depend on age in healthy and physically active males. The magnitude of hypoalgesia appears, at least in part, independent of metabolism or the sympathetic drive during exercise.
Conclusion: Cycling until exhaustion leads to hypoalgesia in exercising muscles. However, the amount of EIH is not uniform but depends on the exercise protocol.

Keywords: Elderly; aerobic exercise; pressure pain; repeated measurement effect.

1. INTRODUCTION

It is well established that physical exercises are able to temporarily reduce pain perception and therefore increase pain thresholds [1]. The range of effectiveness appears to depend on the characteristics of the pain-stimulus, subjects, and exercise. The latter can be specified by the form of muscle-contraction (dynamic, isometric), intensity, and duration. Concerning their contribution on exercise induced hypoalgesia (EIH), the interactions between these parameters are still matter of debate [1]. Hoffman et al. [2] using cycle ergometer protocols of different intensities and durations, postulated that in order to elicit EIH, exercise intensity would have to exceed 50% of maximal oxygen uptake and that exercise duration would have to last longer than 10 minutes. Although to some extend conflicting, the intensity effect could be confirmed by Naugle et al. [3] showing that cycling with 70% of heart rate reserve (HRR) for 20 minutes enhanced pressure pain threshold (PPT) while 25 minutes cycling at 50% to 55% HRR did not.

For a long time EIH was primarily investigated in young and middle-aged subjects [2,3,4,5,6,7,8] although pain perception appears to be influenced by age [9,10]. Gibson and Helme [9] reviewed age-related differences in pain perception and found both clinical and experimental-based evidence for a decreased pain perception with age. Petrini et al. [10] confirmed these results for suprathreshold pressure stimuli but found significantly lower pressure pain thresholds in older males. In spite of these obviously age-related differences it remained unanswered whether the underlying mechanisms correspond to an aging effect itself or to age-attended effects like morbidities or psychosocial influences. However, literature concerning EIH in the elderly still remains rare. Lemley et al. [11] investigated pain thresholds in men older than 60 years and found increases in pain thresholds after isometric contractions of different intensities and durations with no detectable dose-response relationship. An age-mixed study population ranging from 18 to 65 years of both sexes yielded exercise-induced hypoalgesia through isometric contractions, which was not influenced by age [12].

In the present study, we compared the influence of two dynamic cycle-exercises leading to exhaustion but differing in duration and total amount of work on pressure pain thresholds in young and old, physically active males.

2. METHODS

Subjects were recruited via written and verbal advertisements in regional sport clubs. Inclusion criteria were i) male, ii) regular physical training with a frequency of at least two times per week, iii) age between 20 and 30 years or older than 60 years. Exclusion criteria were i) any acute/ chronic pain or illness and ii) cardiovascular limitations for tests until exhaustion. After detailed verbal and written briefing of subjects about the study objectives and risks they gave their written informed consent. The study was approved by the University Ethics Committee.

2.1 Subjects

30 males participated in the study. The two age groups described above were in a range from 20 to 29 years (young group, n = 15) and 60 to 84 years (old group, n = 15). The means and standard deviations of age, height, weight, and body mass index are presented in Table 1.

2.2 Tests

All subjects performed three different tests which were individually separated by at least three days. The workloads for ergometer-cycling (Ergo metrics 900, Ergoline, Germany) were adjusted as follows.

2.2.1 Incremental- load test (ILT)

Workload (WL) was automatically increased every 3 minutes until subjective exhaustion. The initial WL and the stepwise elevation of WL amounted to 25 W in old subjects (modified WHO protocol [13]). For the young group, the first two WL were 50 W and 100 W. Thereafter, workload also stepwise increased by 25 W every 3 min.

2.2.2 Constant-load test (CLT)

The test protocol was developed by our group. All subjects cycled for 30 seconds with 50% of their maximal workload obtained during ILT followed by a stepwise increase to 100% of ILT maximal workload, which was performed until subjective exhaustion.

In addition, subjects performed a control test (COT) to allow for repeated measurement effects on the perception of pressure stimuli. To this end, PPTs were evaluated before and after a period of quiet and relaxed sitting in a chair. From preliminary testing we expected a mean maximal exercise duration of about 7 minutes in CLT. Therefore, in the control test PPTs were investigated at the beginning and in minutes 8 and 11 of sitting in a chair.

2.2.3 Sequence of tests

ILT was applied initially in all subjects to determine individual maximal work load. CLT and COT were performed in random order.

2.3 Measurements

2.3.1 Pressure pain threshold

A handheld pressure Algometer (Force Dial™, Wagner Instruments, Greenwich, USA) was applied before as well as 1 and 4 minutes after each treatment. Pressure increased by about 5 N per second applied with a 1 cm^2 flat rubber tip [3]. Subjects were instructed to say “stop” when the pressure sensation first became painfull. PPTs were determined from the middle part of the thenar as a measure of non-exercising muscles of the body while the middle part of the quadriceps served for detection of pain sensitivity in loaded muscles. The body side investigated was kept constant within subjects for all three trials. All tests were performed by 2 experienced members of our group and the investigator was not changed within the one subject in order to minimize interobserver variability. The mean of three consecutive measurements interrupted by about 30 seconds each was taken for further computations.

2.3.2 Lactic acid concentration ([lac])

At rest and immediately after the end of both exercise tests blood samples were taken from an earlobe and [lac] determined (Accutrend© Lactate Analyser, Roche Mannheim, Germany). During COT no blood samples were drawn.

2.3.3 Heart rate (HR)

HR was recorded by standard ECG-leads via chest electrodes (Cardio direct 12, Del Mar Reynolds Medical, UK). For further computations resting and peak HR were used.

2.4 Statistics

A four way analysis of variance was applied to detect significant factors on PPT (age, test mode, time, and pressure localization). For significant main effects, post hoc tests with Bonferroni-correction were applied. Considering the distribution of data using the Kolmogoroff-Smirnoff-Test, t-Tests or Wilcoxon-Tests were performed. Correlations were computed through one-tailed Pearson Test or one-tailed Spearman’s rank correlations. Level of significance was set to $p \leq 0.05$.

Raw data of PPT and PPT-data corrected for baseline values and effects of repeated measurements were analyzed separately. Corrected values at T1 and T4 were calculated as percentages of T0 for ILT and CLT respectively, and the results subtracted by the respective COT data.

Unless otherwise stated, data are expressed as mean and standard deviation.

3. RESULTS

3.1 Physical Characteristics of Exercises

Maximal work load during ILT amounted to 256 $\pm$ 30 W and 146 $\pm$ 38 W in young and old subjects respectively (significant different with $p < 0.001$). Table 2 depicts the total amount of work for both groups during the exercise tests, which also shows significant differences for both age groups and exercise mode.

3.2 Heart Rate and Lactic Acid Concentrations

Baseline values for HR and [lac] are presented in Table 1. Lactic acid concentrations and heart rates after exercise were not significantly influenced by exercise mode but differed significantly ($p < 0.0001$ and $p < 0.01$, respectively) between young and old subjects (Table 3).

3.3 Pressure Pain Thresholds

Prior to exercise, no significant differences of PPT in the three test conditions could be obtained. The significance of main effects on EIH are presented in Table 4. After correction for repeated measurement effects, pressure location, test mode and time remained significant but their interactions did not.

3.3.1 PPT after treatment in the leg

Both exercise forms led to hypoalgesia in the legs, which was significantly more pronounced in CLT ($p < 0.01$, Fig. 1, top). The comparison of age groups yielded stronger effects in the elderly. While in COT no influence of repeated measurements could be obtained in the young, a significant ($p < 0.05$) increase in PPT occurred in the elderly. After correction of PPT for repeated measurements effects, the percentage data for T1 and T4 still yielded a stronger hypoalgesic effect in CLT but no significant differences occurred between young and old (Fig. 1, bottom).

3.3.2 PPT after treatment in the hand

Pain sensitivity tended to increase in the young except for T1 in the constant load test (Fig 2, top). In contrast, significant decreases in pain sensitivity could be obtained for ILT and COT in the elderly. The allowance for repeated measurement effect resulted in comparable alterations in PPT for young and old with neither significant hyper- nor hypoalgesic effects (Fig. 2, bottom).

In both age groups, individual PPT prior to treatments showed high correlations between tests. That could be confirmed for hand (ILT-CLT: r_{young}= 0.63, r_{old}=0.74, ILT-COT: r_{young}= 0.62, r_{old}=0.59; CLT-COT: r_{young}= 0.85, r_{old}=0.66; all p < 01) and leg (ILT-CLT: r_{young}= 0.61, r_{old}=0.75, ILT-COT: r_{young}= 0.74, r_{old}=0.75; CLT-COT: r_{young}= 0.79, r_{old}=0.50; all p < 01) as well as for hand-leg relationships within tests (ILT-CLT: r_{young}= 0.71, r_{old}=0.71, ILT-COT: r_{young}= 0.59, r_{old}=0.79; CLT-COT: r_{young}= 0.83, r_{old}=0.74; all p < 01). PPT for hand was significantly lower than for leg ($p < 0.01$).

Table 1. Characteristics of subjects at rest. Mean ± SD

Subjects	Young		Old		*P*
Age (years)	24.7± 2.5		71.9±6.5		< 0.00001
Height (cm)	182±4.8		173±3.7		< 0.05
Weight (kp)	78±7.3		75±7		n.s.
BMI (m x kg^{-2})	23.6±1.7		24.9±2.1		n.s.
Test	**Incremental**	**Constant**	**Incremental**	**Constant**	
Heart rate (min^{-1})	75±9.1	77±11.4	73±11.5	69±10.0	n.s.
[lactate] (mmol x l^{-1})	1.8±0.5	1.6±0.4	2.1±0.6	2.2±0.7	n.s.

Table 2. Physical characteristics of exercise. Mean ± SD

Subjects	Young			Old			Young vs. old	
Exercise mode	**Incremental**	**Constant**	***p***	**Incremental**	**Constant**	***p***	***P* incr.**	***P* const.**
Maximal load (w)	256± 30.3			146±37.5			< 0.0001	
Duration (min)	24.7±3.7	7.5± 2.2	<0.0001	17.4± 4.7	4.8± 1.9	<0.0001	<0.001	<0.001
Total work (J)	244± 58.8	119±33.7	<0.0001	94± 42.9	45±24.9	<0.0001	<0.0001	<0.0001

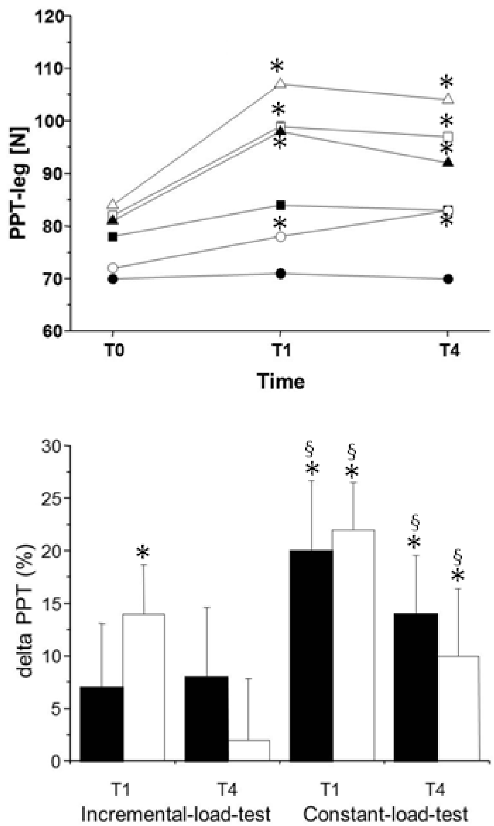

Fig. 1. Upper panel: Mean pressure-point-thresholds at the quadriceps presented as raw data. For better reading, standard errors are not presented (range from 6, 9 N to 10, 6 N)

*Closed symbols: young subjects, open symbols: old subjects, square: ILT; triangle: CLT; circle: COT. Bottom panel: Percentage changes after exercise, corrected for repeated measurement effects (mean ± SE). Closed symbols: young subjects, open symbols: old subjects. T0 = 3 minutes prior to exercise, T1 = 1 minute after exercise, T4 = 4 minutes after exercise. * = significant different from baseline, § = significant different between ILT and CLT*

4. DISCUSSION

The main findings of the present study were as follows:

1. The percentaged amplitudes of EIH in young and old subjects did not differ after adjusting for baseline drifts due to repeated measurement effects,
2. EIH for pressure stimuli were present in active but not in inactive muscles,
3. Although both exercise protocols led to exhaustion with comparable cardiovascular and metabolic peak values, the amount of pressure pain EIH in working muscles were significantly different.

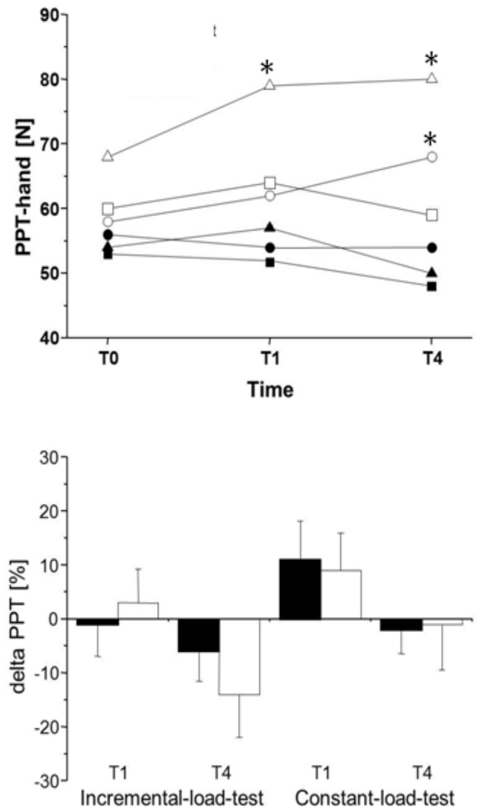

Fig. 2. Upper panel: Mean pressure-point-thresholds at the Thenar presented as raw data. For better reading, standard errors are not presented (range from 2, 85 N to 5, 3 N)

*Closed symbols: young subjects, open symbols: old subjects, square: ILT; triangle: CLT; circle: COT. Bottom panel: Percentage changes after exercise, corrected for repeated measurement effects (mean ± SE). Closed symbols: young subjects, open symbols: old subjects. T0 = 3 minutes prior to exercise, T1 = 1 minute after exercise, T4 = 4 minutes after exercise. * = significant different from baseline, § = significant different between ILT and CLT*

In contrast to Petrini et al. [10] we did not find lower PPTs at rest in the elderly. That may be due to the selection of subjects. In both studies healthy persons were included but the present results were obtained in physically active old males. So, regular exercise may superpose sensory, affective and cognitive pain experiences, which normally occur with age and may change pain perception [10].

Table 3. Peak values of heart rate and lactate concentration. Mean ± SD

Subjects	Young			Old			Young vs. old	
Exercise mode	**Incremental**	**Constant**	***p***	**Incremental**	**Constant**	***p***	***P* incr.**	***P* const.**
Heart rate (min^{-1})	188± 9.9	182± 9.5	n.s.	140± 20.7	139±22.2	n.s.	<0.0001	<0.0001
[lactate] (mmol x l^{-1})	9,2± 1.4	10,7± 1.8	n.s.	6,3± 1.5	6,8± 2.2	n.s.	<0.01	<0.01

Table 4. Significance of factors influencing PPT. Grey areas represent significance levels with p < 0.05

Factor	Significance level for raw PPT. *P* <	Significance level for corrected PPT. *P* <
Localization	0.0001	0.007
Mode	0.001	0.013
Time	0.0001	0.0001
Age	0.139	0.888
Time x Age	0.043	0.104
Time x Mode	0.0001	0.483
Localization x Mode	0.0001	0.979
Localization x Time	0.0001	0.327
Localisazion x Age	0.365	0.921
Mode x Age	0.505	0.988
Localization x Mode x Age	0.190	0.702
Localization x Time x Age	0.773	0.454
Localization x Time x Age	0.602	0.084
Localization x Mode x Time x Age	0.570	0.485

In accordance with the results of Koltyn and Arbogast [14], we did not find a significant effect of repeated measurements in younger adults. In contrast, repeated measurements of pressure pain thresholds led to significant elevations of PPT in old subjects as seen in the control test. That result underlines the postulate of Naugle et al. [1] to include resting control condition in EIH testing. Obviously, that especially becomes important for comparisons between different age groups. After allowing for the repeated measurement effect, the age independence of EIH following dynamic exercise agree with the results of Vaegter et al. [12] obtained after isometric contractions.

Most EIH research subjected to effects of exercise on inactive parts of the body like fingers or arms during and after cycling or running [2,3,15,16]. In the present study we failed to detect any systematic influence on PPTs at the inactive ball of the thumb after allowing for repeated measurement effects but found significant EIH at the middle part of the preceding active quadriceps. Our former result is in contrast to previous research, which yielded EIH effects in non-exercising parts of the body after vigorous exercise [3,15]. Whatever the reason behind the discrepant result is, the present data suggest that in trained men dynamic exercise predominantly evokes local effects on PPT rather than a generalized EIH.

The exercise protocols were designed in such a way that both ILT and CLT should lead to subjective exhaustion. The obtained maximal heart rates and lactic acid concentrations confirm that all subjects reached that goal in both tests. However, in spite of similar maximal heart rates and lactic acid concentrations the influence on PPT in loaded muscles was remarkably different: A significantly higher depression of pain sensitivity could be obtained in the constant load test, which we did not expect since in CLT both the exercise duration and the exercise time spent above 50% of maximal workload and the total work was significantly lower. Some previous studies dealt with the relationship between physical characteristics of exercise and the corresponding EIH [2,4,15,16]. Hoffman et al. [2] postulated intensity thresholds of greater than 50% of VO2 max and durations of greater than

10 minutes. The present data controvert this simple threshold model with independent intensity and duration variables. In the constant load test, we obtained significantly elevated EIH after mean exercise times of 7,5 min and 4,8 min in young and old subjects, respectively. Furthermore, the incremental exercise test was performed for longer than 8 minutes at intensities greater than 70% of the maximal work load in both age groups. Nevertheless, the resulting EIH was significantly lower than in CLT.

Whatever the underlying mechanisms of EIH may be, a close relationship to the activity of the cardiovascular system or metabolism appears unlikely since CLT and ILT reached nearly identical maximal heart rates and lactic acid concentrations despite significantly different EIH.

Limitations of the study: The experiments of Neziri et al. [17] demonstrated that the thresholds of mechanical, electrical, and thermal painful stimuli were just weakly correlated. Therefore, the present findings cannot be generalized for pain perception but only holds for pressure EIH, which appears to be most sensitive to dynamic exercise [1]. Furthermore, since we examined healthy and physically active males, our results cannot be generalized and transferred to other populations.

Since we initially had to evaluate subject´s maximal work load via the incremental load test, ILT and CLT could not be performed in random order. However, for all three tests we did not find any influence of the test sequence on pain thresholds at rest. Therefore, the significant different EIH amplitudes between ILT and CLT may not be importantly attributed to the test sequence.

5. CONCLUSION

Cycling until exhaustion leads to hypoalgesia in exercising muscles. However, the amount of EIH depends on the exercise protocol. This phenomenon cannot be attributed to the total amount of work or maximal work load and is not associated with maximal heart rate or maximal lactic acid concentration during exercise. Further studies are needed to identify predictive parameters of EIH.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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