Osteopathic Manipulative Treatment and Cardiovascular Autonomic Parameters in Rugby Players: A Randomized, Sham-Controlled Trial

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ABSTRACT

Objectives: The purpose of this study was to investigate the effects of osteopathic manipulative treatment (OMT) on cardiovascular autonomic parameters after a rugby match.

Methods: Resting and reactivity (i.e., response to orthostasis) measures of mean arterial pressure, heart rate, and heart rate variability were assessed in twenty-three male players following a single session of OMT, both 18-20 hours after a rugby match and in a corresponding no-match condition, in a randomized, sham-controlled, crossover design.

Results: Signs of reduced heart rate variability, and elevated mean arterial pressure and heart rate were found 18-20 hours after a rugby match compared with a no-match condition. A significant increase in heart rate variability and a significant reduction in mean arterial pressure were observed following OMT both in the after match and no-match conditions. Heart rate and heart rate variability responses to orthostasis were not affected by previous match competition, but were significantly larger following OMT compared with sham treatment.

Conclusion: This study documents the presence of cardiovascular autonomic alterations in rugby players in the aftermath of a competitive match, which may be indicative of prolonged fatigue and incomplete recovery. In these players, favorable changes in cardiovascular autonomic parameters were observed following a single session of OMT, suggesting that OMT may be implemented as a recovery strategy to restore players' cardiovascular autonomic homeostasis after a rugby match.

Keywords: autonomic; cardiovascular; osteopathy; recovery; rugby

INTRODUCTION

It is well known that substantial cardiac autonomic adjustments must occur during exercise to meet the competing demands of working muscles (metabolic demands) and skin blood flow (thermoregulatory demands), while maintaining blood pressure and adequate perfusion to other organs.[1] Upon exercise termination, there is an immediate cessation of mechanical, chemical and thermal stimuli on the body that leads to partial cardiac autonomic recovery.[2] However, complete recovery occurs only after chemical, humoral and thermoregulation factors have returned to normal levels.[3,4]

A few studies have found that higher exercise intensities delay the recovery of heart rate (HR) and HR variability (HRV, a surrogate marker of cardiac autonomic function) in the immediate hours that follow exercise cessation in both athletes and sedentary subjects.[4-7] These cardiac autonomic changes are particularly evident in situations where the physical demands associated with high exercise intensities are associated with high psychological demands, as, for example, during competitive match play.[8,9] Indeed, elevated HR and reduced HRV have been described in soccer and rugby league players, and soccer referees for up to 10-24 hours following the match.[10-12] Moreover, a previous study documented a reduced ability of the autonomic nervous system (ANS) (i.e., smaller HRV changes) to respond to an orthostatic challenge (i.e., active standing) on the days following a competitive rugby league match.[12]

Importantly, similar alterations in resting and reactivity measures of cardiac autonomic function have been associated with overtraining syndrome and illness in elite athletes,[13-15] suggesting that incomplete cardiac autonomic recovery after competitive match play may have potential negative consequences on subsequent training and overall performance. This warrants the investigation of effective interventions aimed at facilitating a faster recovery of athletes' cardiac autonomic homeostasis in the aftermath of a competitive match.

Osteopathic manipulative treatment (OMT) is a form of non-invasive manual treatment that uses a set of touch, manipulation and mobilization procedures to diagnose, treat, and prevent illness or injury.[16] For many years, investigations on manual therapy techniques focused on understanding their psychophysiological mechanisms and their clinical effects.[17-19] Specifically, a theoretical basis for the effects of OMT on the body has been advanced based on its action on the ANS, which causes concomitant vasodilatation, smooth muscle relaxation, and increased blood flow, resulting in improved range of motion, decrease in pain perception, and/or change in tissue.[20,21] However, it was not until recently that the theoretical association between OMT and ANS activity was supported by empirical evidence showing that OMT leads to an increase in HRV at rest and counteracts stress-induced HRV reduction in healthy individuals.[22-25] These results appear consistent with a larger body of literature which documents similar ANS responses (e.g., increased HRV and decreased systolic blood pressure) to other forms of manual therapy, particularly spinal manipulative therapy, both in asymptomatic individuals and patients complaining of neck or back pain.[26-31] The documented ability of manual therapy techniques to induce ANS activation under several conditions represents an opportunity to study the effects of OMT in the context of cardiovascular autonomic recovery after competitive match play.

Specifically, the main objective of the current study was to investigate the effects of a single session of OMT on resting and reactivity measures of cardiovascular autonomic function (i.e., HRV, HR and blood pressure) in trained adult male players long after (18-20 hours) a rugby union match. Anticipating signs of reduced HRV, and elevated HR and blood pressure in the aftermath of the match, we hypothesized a normalization of these resting parameters following OMT. Moreover, we tested the hypothesis that OMT would be associated with greater cardiac autonomic reactivity to an orthostatic challenge (i.e., head-up tilt test).

METHODS

Participants

Recruitment. Volunteers from three male rugby union teams competing in the second (i.e., “Serie A”) and third (i.e., “Serie B”) tier of the 2017-2018 Italian Rugby Union championship were recruited from October 01, 2017 to October 31, 2017 through direct contact. Initially, all players of these teams received written information and a verbal explanation about the nature and purpose of the study and were invited to take part in it.

Inclusion/Exclusion Criteria. Inclusion criteria included: (i) being healthy and injury-free, (ii) age ≥ 18 years old, (iii) being Caucasian (to reduce variability related to ethnic differences in HRV and blood pressure regulation),[32,33] (iv) regular participation in competitive matches of rugby union consisting of 2, 40-min halves, and (v) regular training for an average of six hours/week during the last four weeks. Exclusion criteria included: (i) history of cardiovascular disease or traumatic brain injury, (ii) chronic drug treatment, (iii) use of any medications during the last week, and (iv) having received OMT before.

Study settings. The study took place at the Italian College of Osteopathy in Parma, Italy.

Ethics. Written informed consent was obtained from all players prior to participation with ethics approval granted from the independent institutional review board of the Foundation COME Collaboration (authorization n° 032017) in accordance with the 1964 Helsinki declaration and its later amendments. This trial has been registered at http://clinicaltrials.gov/ (identifier NCT04242485).

Study Design

The present study adopted a randomized, double-blind, sham-controlled, crossover design to test each player four times in two different conditions, namely after match and no-match (Figure 1). In the after match condition, players undertook a recording session (see below) 18 to 20 hours after their participation in a competitive match of rugby union, which took place between 3 pm and 6 pm of the preceding day. In the no-match condition, players undertook a recording session (see below) the day after a resting day in which they had not done any intense or sustained physical activity as determined from a pre-screening questionnaire. Every player was tested twice in the after match condition and twice in the no-match condition, at the same time of the day (between 10 am and 1pm).

For each condition, after baseline recordings, players were randomly assigned to OMT or sham treatment (Figure 2). Randomization of conditions and treatments was performed according to a computer-generated table by a researcher not involved in the intervention sessions. Thus, each player undertook four recording sessions: (1) after match + OMT, (2) after match + sham, (3) no-match + OMT, and (4) no-match + sham (Figure 1). In addition, a one-week washout period between recording sessions was employed. The after match recording session (see below) could be rescheduled if the participants had not completed a minimum of 60 min of match play. Subjects were considered drop-out in case they did not meet this requirement at the rescheduled session or in case of nonattendance.

Sample Size

The primary study outcome measure of HRV was used for calculation of the required sample size using G*Power Version 3.1.[34] This was based on pilot study data suggesting an effect size (Cohen's dz) of 0.65 for HRV measured before and after a single session of OMT in the aftermath of a rugby match. To achieve a power of 80% at an alpha level of 0.05 a total of 21 players was required to detect meaningful within-subject changes in HRV. Therefore, to account for up to a 20% withdrawal rate, a total of 26 players were recruited.

Blinding

Players were blinded to study design and treatment allocation (OMT or sham). Osteopaths were blinded to players’ conditions (i.e., after match or no-match). Data collection and analysis were conducted by a researcher who was blinded to players’ conditions (after match or no-match) and treatments (OMT or sham).

Procedure

Participants were asked not to perform physical activity the day of the recording session and to refrain from caffeine and alcohol consumption or smoking at least 12 hours prior to the recording session, as these variables may have transient effects on cardiovascular measurements.[35] The sequence of procedures adopted in this study is depicted in Figure 2. Upon their arrival to the laboratory, players were instrumented with a BT16Plus device

(Francesco Marazza Hardware & Software, Monza, IT), which allows real time acquisition of the ECG signal (sampling frequency: 250 Hz) through 2 electrodes secured to the right and left parasternal regions and a third reference electrode secured on the right side of the groin area. Moreover, an electronic sphygmomanometer (A&D Medical: Model UA-631 V) was positioned on players' non-dominant arm. Players were then asked to lie supine, with a pillow supporting the head, and refrain from moving or talking for the entire duration of the recording session. After this adaptation phase which lasted 15 min, the cuff inflated and systolic blood pressure (SBP) and diastolic blood pressure (DBP) were measured three times alongside recording of the ECG signal for 10 min. Subsequently, players received either OMT or sham treatment (see below for details) for 30 min, in a randomised sequence. After the treatment, the cuff inflated and SBP and DBP were measured again for three times. ECG recordings resumed during the following three 5-min phases: post-treatment, with the players lying supine; tilt test, with the players being tilted head-up at 60° on a special motorized table; recovery, with the players back in supine position.

Intervention

Players received either OMT or sham manipulative treatment protocols, both of which lasted for 30 min and were performed by two osteopaths with the same educational curricula and experience (each osteopath was randomly assigned to a player and followed him to the end of the study). At the start of each OMT or sham protocol session, players received a 10-min structural evaluation of the pelvis, abdomen, cervical spine, dorsal spine, lumbar spine, sacrum, and upper and lower limbs to diagnose somatic dysfunction as characterized by altered TART (tenderness, asymmetry, range of motion, tissue texture alteration) parameters.[36] Subsequently, for the OMT protocol, the osteopaths treated the specific somatic dysfunction found on structural evaluation for 20 min using OMT techniques that were left at their discretion, including the myofascial release and cranial sacrum techniques,[37] following a rationale grounded on the notion that "*the therapeutic application of manually guided forces…[is crucial] to improve physiological function and homeostasis that* *has been altered by somatic dysfunction*".[38] Alternatively, for the sham protocol, the osteopaths placed both hands on a sequence of body regions of the players that included the pelvis, abdomen, cervical spine, dorsal spine, lumbar spine, sacrum, and upper and lower limbs. Each region was gently touched for 2-3 min without the use of any specific treatment,[39] and total contact time with the osteopath was the same as the OMT condition (20 min). It is worth noting that before the start of the study, the two osteopaths underwent a 4-hour training session to familiarise with and consistently reproduce the sham protocol.

Outcomes

Resting measures of HRV, HR and blood pressure in the aftermath of a rugby match and following a single session of OMT were considered the primary outcomes of the study. HRV and HR responses to the tilt test in the aftermath of a rugby match and following a single session of OMT were considered the secondary outcomes of the study.

***HR and HRV Analysis*.** ECG signals were amplified, converted to digital, and analysed with Chart5 software (ADInstruments, Sydney, Australia) in 5-min epochs. Initially, each raw ECG signal was manually inspected to ensure that all R-waves were correctly detected. Then, we calculated HR plotting the number of R waves per unit time (reported in beats per minute; bpm). Subsequently, we quantified time- and frequency-domain parameters of vagally-mediated HRV, namely the root mean square of successive beat-to-beat interval differences (RMSSD, ms) and the power of the high frequency band (HF; 0.15–0.4 Hz; ms^2), respectively.[40]

***Blood Pressure Analysis*.** SBP and DBP values obtained via sphygmomanometery were averaged and transformed into mean arterial pressure (MAP) using a standard formula: $\sum (DBP + 1/3 (SBP - DBP))$.

Data Processing and Statistical Analysis

Statistical analyses were performed using SPSS 25 software package (SPSS Inc., Chicago, IL, USA). Statistical significance was set at $p<.05$. Assumptions for normality were tested for all continuous variables using the Shapiro-Wilk test. We accounted for non-normal distribution of RMSSD and HF values ($p<.001$) by calculating their natural logarithm (lnRMSSD and lnHF). Pearson correlation coefficients were computed between resting (i.e., pre-treatment) MAP, HR, lnRMSSD, and lnHF values corresponding to the two after match and the two no-match conditions, respectively. Given the high correlation coefficients ($0.75<r<0.83$) found between cardiovascular parameters obtained in the same resting condition, average MAP, HR, lnRMSSD, and lnHF resting values were calculated for each player for the after match and no-match condition.

Subsequently, to evaluate alterations in resting cardiovascular parameters following a rugby union match, a series of general linear models (GLMs) were applied, with “condition” being the within-subject factor (two levels: after match or NO-MATCH), controlling for the effects of smoking status.

The effects of OMT and sham treatment on resting cardiovascular parameters were calculated as delta values (i.e., the differences between post-treatment MAP, HR, lnRMSSD, and lnHF values and the corresponding pre-treatment values) and analysed by means of a series of 2 (after match or no-match) × 2 (OMT or sham) GLMs, controlling for the effects of smoking status.

Finally, HR, lnRMSSD and lnHF responses to the tilt test and the following recovery phase were evaluated as delta values (i.e., tilt test value – pre-tilt resting value and recovery value – pre-tilt resting value) and analysed by means of a series of 2 (after match or no-match) × 2 (OMT or sham) x 2 (tilt test or recovery) GLMs, controlling for the effects of smoking status.

RESULTS

Participants Characteristics

In total 23 participants completed the study and provided data for the analysis (Figure 1). Their average age and body mass index were, respectively, 24.1 (SD=4.8) years and 30.8 (SD=4.9) kg/m^2; 26% of them were occasional smokers.

Resting Cardiovascular Parameters After a Rugby Union Match

The after match condition was characterized by significantly higher resting values of MAP ($F=5.3$, $p<.05$, $\eta_p^2=0.201$ (Figure 3A) and HR ($F=9.3$, $p<.01$, $\eta_p^2=0.307$) (Figure 3B), and significantly lower resting values of lnRMSSD ($F=8.43$, $p<.01$, $\eta_p^2=0.286$) (Figure 3C) and lnHF ($F=11.1$, $p<.01$, $\eta_p^2=0.346$) (Figure 3D) compared with the no-match condition.

Resting Cardiovascular Parameters Following OMT

The GLM applied to delta MAP values yielded a significant effect of treatment ($F=12.7$, $p<.01$, $\eta_p^2=0.256$), with a significantly larger reduction in resting MAP values after OMT than sham treatment both in the after match ($p<.01$, $\eta_p^2=0.185$) and no-match ($p<.05$, $\eta_p^2=0.121$) condition (Figure 4A).

As for delta HR values, we found a significant effect of condition ($F=4.9$, $p<.05$, $\eta_p^2=0.117$), and only a marginally significant effect of treatment ($F=3.3$, $p=.07$, $\eta_p^2=0.082$). In other words, the reduction in resting HR values was larger in the after match condition compared to the no-match condition independently from OMT or sham treatment (after match: -5.2±0.9 bpm vs no-match: -2.9±0.9 bpm, $F=9.8$, $p<.05$, $\eta_p^2=0.121$) (Figure 4B).

The GLM applied to delta lnRMSSD values yielded a significant effect of treatment ($F=6.8$, $p<.05$, $\eta_p^2=0.347$), with a significantly larger increase in resting lnRMSSD values after OMT than sham treatment both in the after match ($p<.05$, $\eta_p^2=0.114$) and no-match ($p<.05$, $\eta_p^2=0.138$) condition (Figure 4C).

As for delta lnHF values, we found a significant effect of treatment ($F=5.6$, $p<.05$, $\eta_p^2=0.132$), with a significantly larger increase in resting lnHF values after OMT than sham treatment only in the after match condition ($p<.05$, $\eta_p^2=0.124$) (Figure 4D).

Cardiac Autonomic Responses to the Tilt Test

The GLM applied to delta HR values yielded a significant effect of time ($F=43.9$, $p<.01$, $\eta_p^2=0.543$). As expected, there was an increase in HR values during the tilt phase, with no significant effects of condition (after match or no-match) or treatment (sham or OMT) (Figure 5A).

As for delta lnRMSSD values, we found a significant effect of time (F=45.0, p<.01, η_p^2=0.554) and a time x treatment interaction (F=4.2, p<.05, η_p^2=0.107). As expected, there was a decrease in lnRMSSD values during the tilt phase, which was significantly larger after OMT than sham treatment independently from condition (i.e., after match or no-match) (OMT= -0.78±0.09 vs sham= -0.48±0.08, F=5.9, p<.05, η_p^2=0.138) (Figure 5B). Similarly, the GLM applied to delta HF values yielded a significant effect of time (F=46.6, p<.01, η_p^2=0.557) and a significant time x treatment interaction (F=5.5, p<.05, η_p^2=0.129). As expected, there was a decrease in lnHF values during the tilt phase, which was significantly larger after OMT than sham treatment independently from condition (i.e., after match or no-match) (OMT= -1.49±0.25 vs sham= -0.77±0.20, F=5.1, p<.05, η_p^2=0.122) (Figure 5C).

Harms

No adverse events or unintended effects were reported following OMT or sham treatment.

DISCUSSION

The major and novel finding of the current study is the presence of increased resting and reactivity measures of HRV and reduced resting MAP following a single session of OMT in rugby players, both in the aftermath of a competitive match and in a no-match control condition.

Rugby union is a high-intensity team sport during which players perform repeated high intensity efforts such as sprints, high-impact collisions, and rapid changes of direction. Not surprisingly, we found signs of reduced vagally-mediated HRV, and elevated MAP and HR, during the assessment of resting cardiovascular parameters 18-20 hours after a rugby union match in trained players. These results confirm, and further extend, previous research demonstrating lower vagal-related HRV indexes for up to 10-24 hours following soccer or rugby league matches.[10-12] Other studies have shown that while the decrease of HR and sympathetic predominance is fast at the end of an exercise, it takes several minutes, even several hours to recover the initial level of resting cardiac autonomic balance.[41,42] This physiological adaptation is essential to maintain an important blood flow in active muscles to remove metabolic waste produced during exercise, especially during competitive conditions.[43] The delay of returning to a basal state of sympathovagal balance seems dependent on the intensity of the exercise, because it was found to be more important after higher than lower exercise intensities, and may involve the arterial baroreflex and its sensibility.[4] Therefore, signs of cardiac autonomic imbalance in the aftermath of an intense exercise performed during a competitive match may indicate incomplete recovery and prolonged fatigue. Indeed, physical markers of fatigue (e.g., reduced jump peak power) have been described in rugby league players for up to 48 hours after match play.[44]

The combative nature of rugby union combined with high intensity efforts is synonymous with repeated blunt force trauma and post-match muscle soreness. Given the negative relationship found between acute and chronic pain and vagally-mediated HRV,[45,46] it is plausible that signs of reduced vagally-mediated HRV after a rugby match may also be a consequence of post-match aches and pains. Notably, a sustained elevation of cortisol levels has also been described in the 24 hours that follow a rugby league match.[47] Taken together, these findings indicate an incomplete return to hormonal and cardiovascular homeostasis for at least 24 hours after exposure to physical and psychological stress associated with rugby match play.

Contrary to our expectations, we did not find post-match changes in cardiac autonomic reactivity to an orthostatic challenge. This is in disagreement with a previous study documenting a reduced ability of the ANS (i.e., smaller HRV changes) to respond to orthostasis on the days following a competitive rugby league match.[12] A potential explanation for this discrepancy lies in the difference between the orthostatic challenge adopted by the Edmonds' study (i.e., active standing) and the present study (i.e., 60° passive head-up tilting). It must also be acknowledged that the assessment of blood pressure changes, as well as of baroreflex activity, during the orthostatic challenge would have provided a more complete picture of the ability of the cardiovascular system to adapt to postural changes the day after a rugby match.

The implementation of recovery strategies in the aftermath of a rugby match may be beneficial to restoring players' physiological systems for greater adaptations to subsequent training and enhanced overall performance. In this context, the main objective of this study was to evaluate the effects of a single session of OMT on resting and reactivity measures of cardiovascular autonomic function after a rugby union match. Notably, we found an increase in resting measures of vagally-mediated HRV following OMT compared to sham treatment, particularly in the after match condition. Moreover, a significant decrease in resting MAP values was found following OMT, but not sham treatment, both in the after match and no-match condition. Changes in resting HR after OMT were somewhat less evident. This was due to the fact that the sham treatment that we adopted in this study (i.e., "soft touch" without applying any pressure) was also associated with a reduction in HR and, partly, an increase in vagally-mediated HRV, which is in line with previous studies.[23,25] Lastly, we found greater cardiac autonomic responses (i.e., larger HRV changes) to the orthostatic challenge following OMT compared to sham treatment, independently from previous competitive participation in a rugby union match.

These results are in line with a growing body of research showing an increase in vagally-mediated HRV at rest or during a stressful challenge after OMT, independently from the part of the body to which it is applied.[22-25] Moreover, we extend this previous research by showing that OMT is associated with reduced MAP in healthy normotensive individuals. Moreover, these results are consistent with previous research documenting an increase in vagally-mediated HRV and a decrease in systolic blood following other forms of manual therapy, particularly spinal manipulative therapy, both in asymptomatic individuals and patients complaining of neck or back pain.[26-31] Taken together, these pieces of evidence support the view that manual therapy techniques, including OMT, can induce ANS activation under several conditions.

In the current study we did not investigate the mechanisms underlying the changes in cardiovascular autonomic parameters following OMT. A previous study, which explored the association between OMT and hypertension, found that OMT (in addition to routine care) was associated with improved intima media thickness and systolic blood pressure after one-year follow-up.[18] The authors of this study suggested that in the presence of trauma or somatic dysfunction changing the structure of the tissue, OMT, consistently with in-vitro models,[48] may decrease the production of inflammatory cytokines, generating a cascade effect on mechanisms that generally improve the metabolism of the arterial wall and activate the ANS.[18,23,49] Consequently, we speculate that the cardiovascular changes observed following OMT in this sample of rugby players may involve indirect mechanisms, including a reduction of post-match soreness and inflammation through correction of somatic dysfunctions, or direct mechanisms, including activation of c-tactile afferent projections to brain stem nuclei involved in the autonomic control of cardiovascular function, or a combination of both.[50,51]

Limitations

The results of this study must be interpreted within the context of their limitations. First, we did not quantify other subjective (e.g., rating of perceived exertion) and/or objective (e.g., blood lactate) measures to characterize the psychophysiological overload caused by the rugby match. Also, we did not measure pain or soreness, which may have helped elucidate a potential indirect effect of OMT on cardiovascular function. Similarly, measurements of blood lactate or pH may have helped raise hypotheses about another potential indirect effect of OMT on the ANS via improvements of lactate removal and overall metabolic recovery. Second, the sample size is relatively small and a type II error is possible. However, we adopted a within-subjects design to reduce error variance associated with individual differences and increase statistical power. Nevertheless, future research should involve a randomized clinical trial with a larger sample size. Third, we did not examine the time course of post-match changes in cardiovascular parameters, but restricted our observation to a specific time window. Further, due to practical/logistic reasons, OMT and sham treatment were performed by two osteopathic practitioners, which might have affected protocol homogeneity. Lastly, players' perception of treatment allocation was not assessed and may have changed during the study, even if "treatment context" (similar contact time with osteopaths and settings) was similar between OMT and sham treatment. Therefore, it would be important to ascertain whether changes in cardiovascular parameters might be ascribable to changes in attributed self-relevance and efficacy of the received treatment. Future studies are needed to clarify all these aspects.

CONCLUSION

The present results add to a growing body of literature documenting the development of alterations in cardiovascular autonomic parameters following a competitive rugby union match in trained players. Moreover, these results suggest the presence of increased resting and reactivity measures of HRV and reduced resting MAP following a single session of OMT in rugby players, both in the aftermath of a competitive match and in a no-match condition. This warrants the investigation of the potential underlying mechanisms, which at present are largely unknown. Notwithstanding the above reported limitations, OMT holds promise as a strategy to promote a faster cardiovascular autonomic recovery from a rugby union match, but its efficacy and applicability to other sports and/or conditions characterized by cardiovascular alterations and autonomic imbalance requires further investigation in larger studies.

Figure legends

Figure 1. Flow chart.

Figure 2. Timeline of the experimental procedures adopted in this study. Abbreviations: OMT = osteopathic manipulative treatment.

Figure 3. Resting cardiovascular parameters in the no-match and after match conditions. Data are expressed as means ± SEM. Abbreviations: MAP = mean arterial pressure; lnRMSSD = natural logarithm of the root mean square of successive beat-to-beat interval differences; lnHF = natural logarithm of the high frequency band. # indicates a significant difference between the two conditions ($p<.05$).

Figure 4. Changes induced by OMT and sham treatment on resting cardiovascular parameters in the no-match and after match conditions. Data are expressed as means ± SEM. Abbreviations: OMT = osteopathic manipulative treatment; MAP = mean arterial pressure; lnRMSSD = natural logarithm of the root mean square of successive beat-to-beat interval differences; lnHF = natural logarithm of the high frequency band. * indicates a significant difference between OMT and the "same condition" sham treatment ($p<.05$); # indicates a significant difference between the no-match and after match conditions ($p<.05$).

Figure 5. Cardiac autonomic responses to the 60° head-up tilt test. Data are expressed as means ± SEM of delta values, which were calculated as the difference between tilt/recovery values and their respective pre-tilt resting values. Abbreviations: OMT = osteopathic manipulative treatment; lnRMSSD = natural logarithm of the root mean square of successive beat-to-beat interval differences; lnHF = natural logarithm of the high frequency band. * indicates a significant difference between OMT and sham treatment ($p<.05$).

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Figure 1

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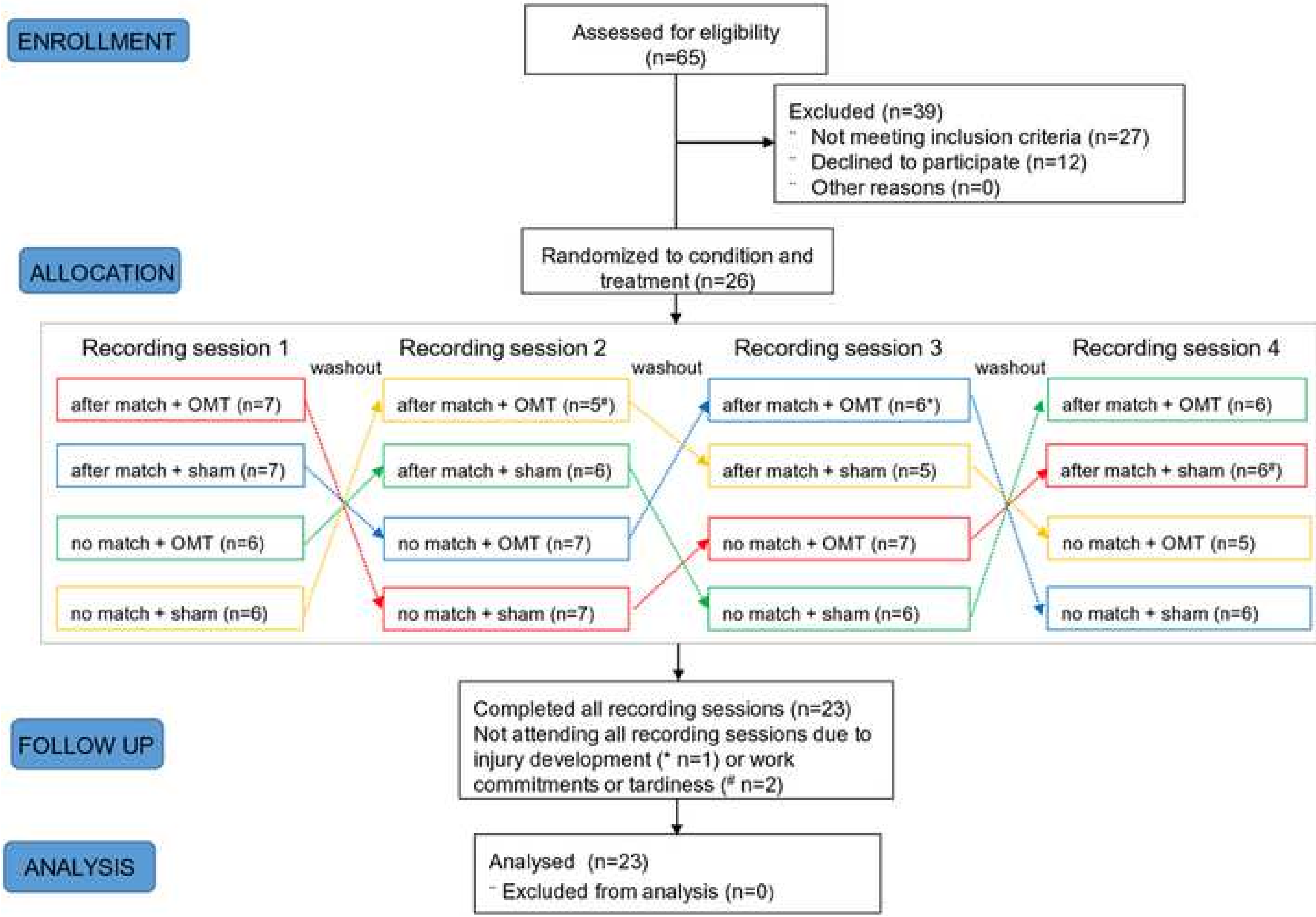


Figure 2

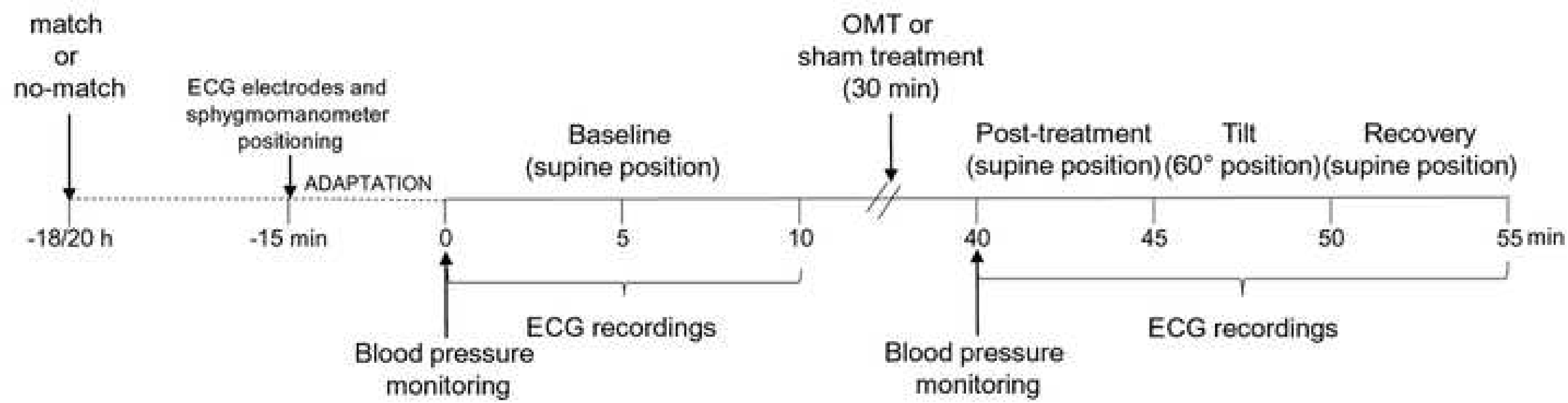

match
or
no-match
ECG electrodes and
sphygmomanometer
positioning
ADAPTATION
Baseline
(supine position)
OMT or
sham treatment
(30 min)
Post-treatment
(supine position)
Tilt
(60° position)
Recovery
(supine position)
-18/20 h
-15 min
0
5
10
40
45
50
55 min
ECG recordings
Blood pressure
monitoring
ECG recordings
Blood pressure
monitoring

Figure 3

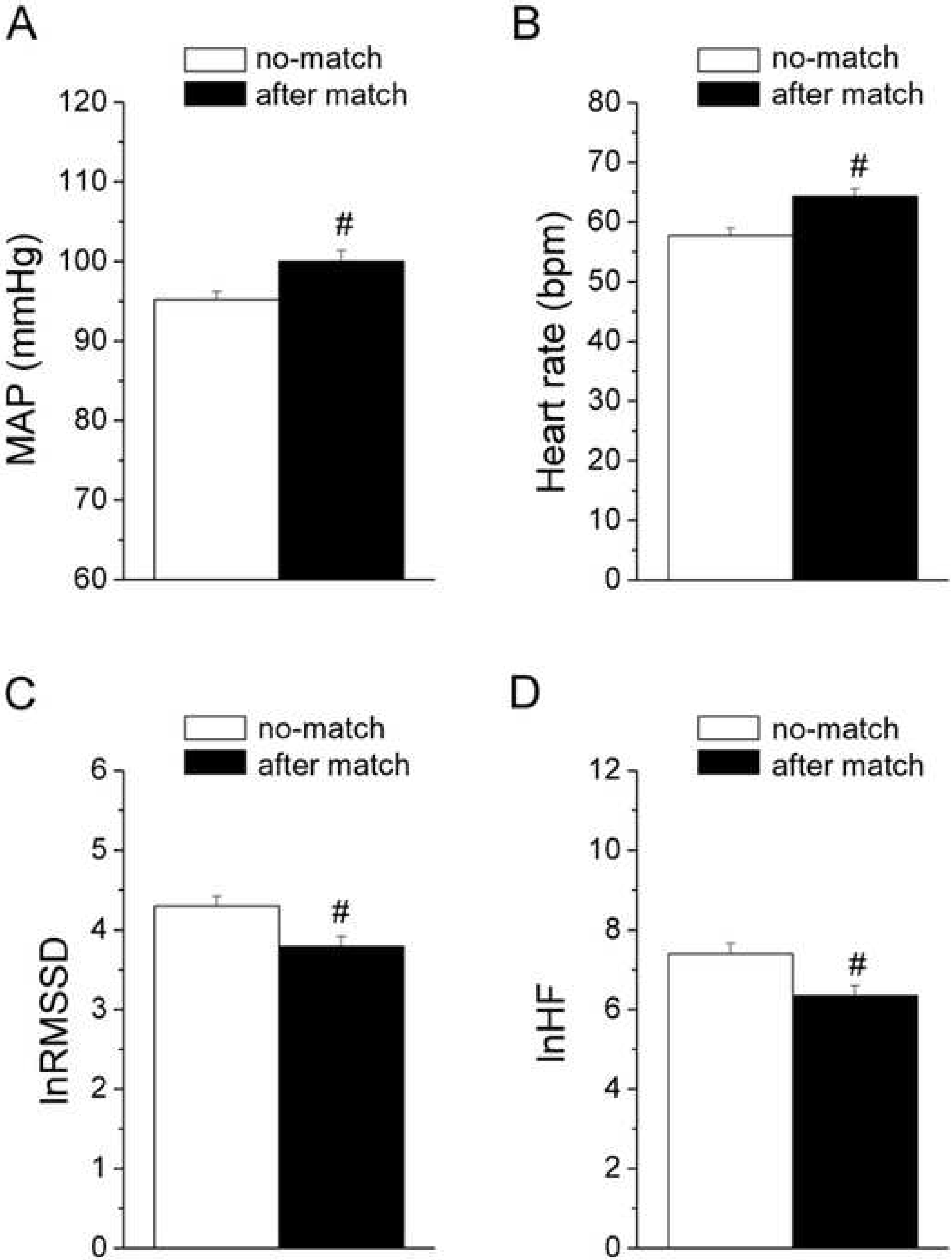

A
no-match
after match
MAP (mmHg)
#
B
no-match
after match
Heart rate (bpm)
#
C
no-match
after match
lnRMSSD
#
D
no-match
after match
lnHF
#

Figure 4

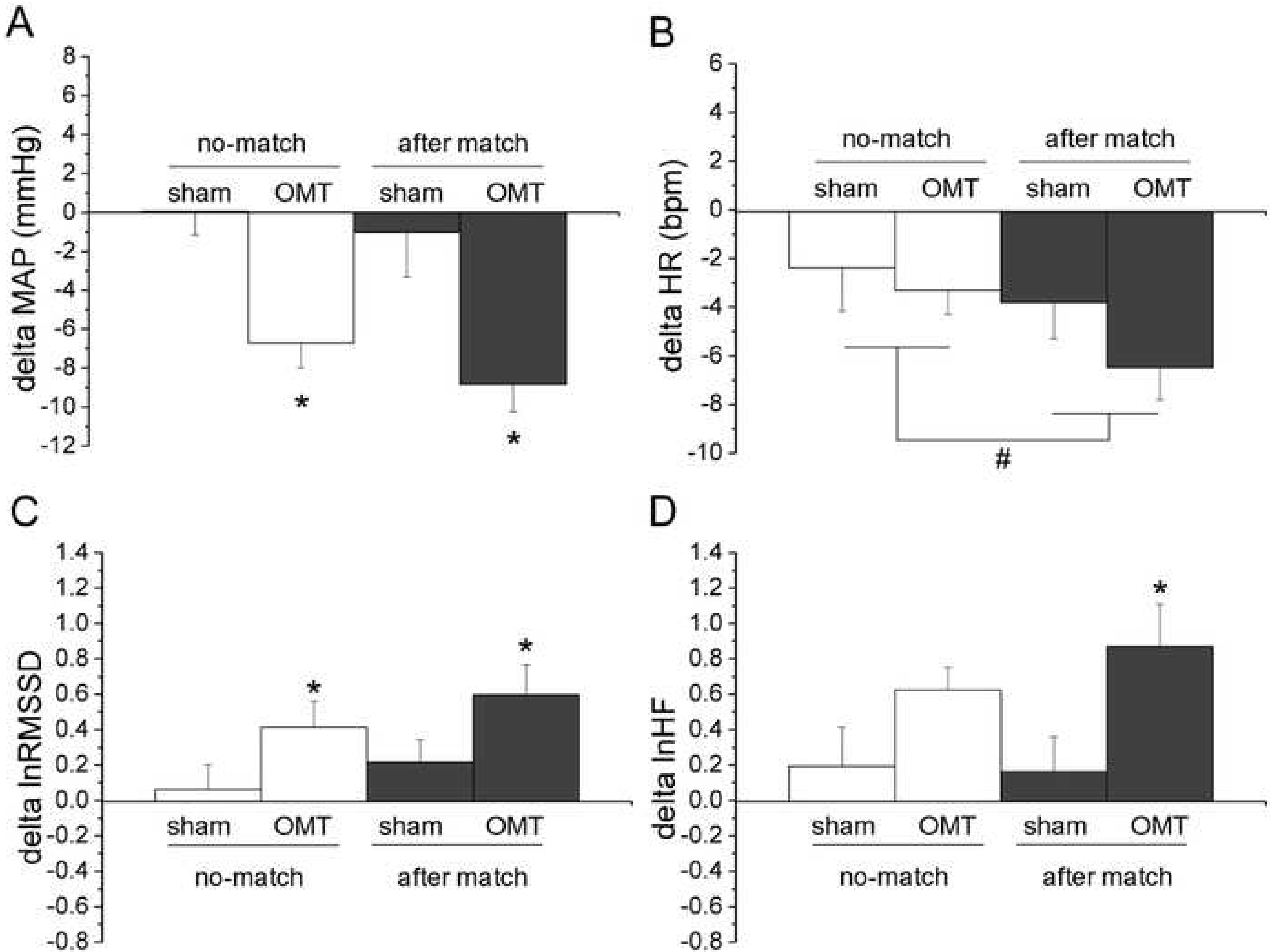
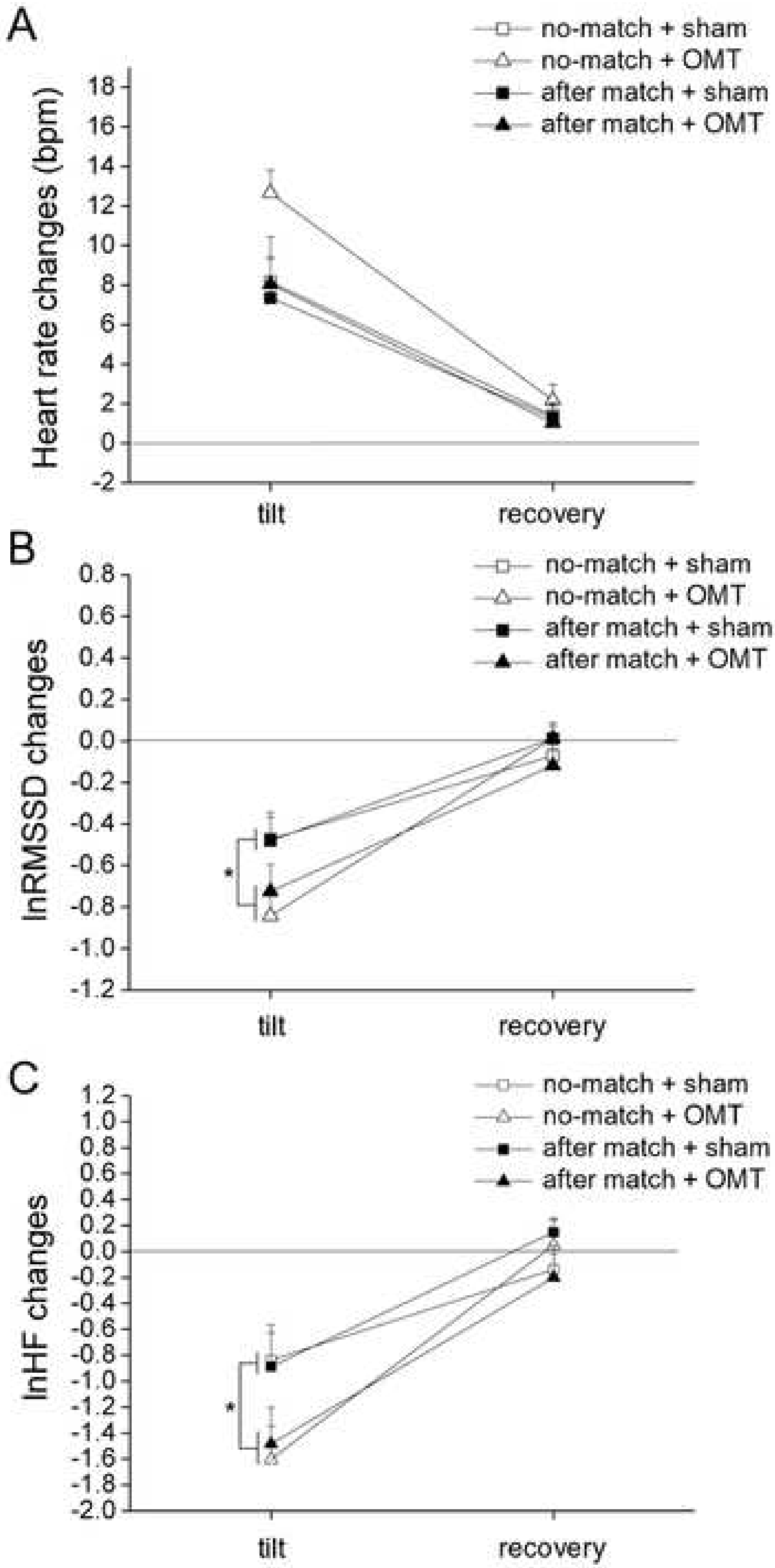

A
delta MAP (mmHg)
8
6
4
2
0
-2
-4
-6
-8
-10
-12
no-match
after match
sham
OMT
sham
OMT
*
*
B
delta HR (bpm)
6
4
2
0
-2
-4
-6
-8
-10
no-match
after match
sham
OMT
sham
OMT
#
C
delta lnRMSSD
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
*
*
sham
OMT
sham
OMT
no-match
after match
D
delta lnHF
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
*
sham
OMT
sham
OMT
no-match
after match

Figure 5


A
no-match + sham
no-match + OMT
after match + sham
after match + OMT
Heart rate changes (bpm)
18
16
14
12
10
8
6
4
2
0
-2
tilt
recovery
B
no-match + sham
no-match + OMT
after match + sham
after match + OMT
lnRMSSD changes
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
*
tilt
recovery
C
no-match + sham
no-match + OMT
after match + sham
after match + OMT
lnHF changes
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
-1.8
-2.0
*
tilt
recovery