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High-sensitivity cardiac troponin T release after a single bout of high-intensity interval exercise in experienced marathon runners

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ABSTRACT

Objective: The purpose of this study was to investigate the effects of a single bout of high-intensity interval exercise (HIIE) on high-sensitivity cardiac troponin T (hs-cTnT) release and to explore the potential influencing factors.

Methods: Twenty-one experienced marathon runners completed HIIE on treadmill. Each bout of HIIE included a hard run ($15.8 \pm 1.3 \text{ km} \cdot \text{h}^{-1}$) at 90% $\text{vVO}_{2\text{max}}$ for 2 min followed by an easy run ($8.8 \pm 0.7 \text{ km} \cdot \text{h}^{-1}$) at 50% $\text{vVO}_{2\text{max}}$ for 2 min performed 23 times within 92 min. Heart rate (HR) was recorded every 2 min during HIIE. The hs-cTnT level was measured before (pre), immediately after (0 h), and at 4 and 24 h after exercise.

Results: The hs-cTnT level was elevated at 0 h, peaked at 4 h, and had not returned to the baseline value at 24 h after exercise. The response of hs-cTnT at 4 h was positively related to exercise HR. Subjects with a greater increase in hs-cTnT level had a higher exercise HR under fixed exercise intensity.

Conclusion: HIIE at 90% $\text{vVO}_{2\text{max}}$ interspersed with 50% $\text{vVO}_{2\text{max}}$ for recovery can elicit hs-cTnT elevation. HR is a good predictor of exercise-induced cardiac troponin (cTn) release under fixed exercise intensity. Further study should consider to correct for HR when constructing impact factors contributing to exercise-induced cTn release.

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1. Introduction

Cardiac troponin (cTn) is a highly specific and sensitive biomarker for the identification of cellular damage or injury in the diagnosis of acute myocardial infarction.^{1,2} Exercise is possibly the only documented cause of cTn release that is not associated with an adverse clinical outcome.³ Many reports suggested that cTn increased in 0% to 100% of subjects,^{4,5} peaked at 3 to 4 h and rapidly returned to baseline level within 24 h after the completion of

intense exercise.⁶ Exercise-induced cTn release is related to exercise intensity and duration, age, training experience, cardiovascular disease, and the environment.^{7–10} Transient changes in membrane permeability may be responsible for the release of unbound cTn from the cytosolic pool of cardiomyocytes,¹¹ but the mechanism is still under debate. The factors that may affect the increase in cTn require further investigation to determine the mechanism and clinical relevance of such exercise-induced perturbations.

From the existing evidence, it seems that exercise intensity, mostly evaluated by heart rate (HR), is a predictor of cTn elevation,^{12–14} but this has not been confirmed in other studies.^{15,16} One reason for this inconsistency is that there seems to be a threshold of exercise intensity at which cTn may not be released at

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a low HR.¹⁷ Furthermore, exercise-induced cTn release, including cardiac troponin T (cTnT) and I (cTnI), subunits of cTn, has been predominantly observed in field-based settings, during which exercise intensity including running velocity and HR are hard to manipulate and instantly record. Consequently, it is impossible to show the respective independent effects of exercise intensity and HR *per se* on the changes of cTn. Actually, cTnT elevation is primarily dependent on HR when tachycardia is present in patients with no coronary disease.¹⁸ Therefore, it is necessary to survey the independent effect of HR on cTn release during exercise.

High-intensity interval exercise (HIIE) performed at an intensity associated with competition pace and maximal oxygen consumption (VO_{2max}) is a training method commonly used by experienced runners. In contrast to constant running at a steady state and submaximal intensity, HIIE places a fluctuated workload on the myocardium, during which intensity can be sustained at a higher level than that attained during constant exercise load.¹⁹ Various HIIE protocols, that of repeated bouts of 1 to 8 min of hard running at 90% to 100% VO_{2max} , have proven to be effective in improving the VO_{2max} of experienced runners,^{19–24} and HIIE has also been found to benefit cardiorespiratory fitness in non-athletes.²⁵ To date, the data on exercise-induced cTn release during interval exercise mode are very limited and inconsistent.²⁶ In field-based settings, cTn elevation was observed after basketball,²⁷ floorball,²⁸ and sprints²⁹ but not after rugby, football,³⁰ and indoor soccer matches.³¹ Research on cTn change induced by HIIE in a laboratory-based setting remains limited. Lu and colleagues reported no significant change in cTnI after 7 intervals of a 2-min run at 90% VO_{2max} interspersed by 1-min recovery periods.³² Due to the development of a high-sensitivity cardiac troponin T (hs-cTnT) assay, it is now possible to reliably detect changes in cTnT at low levels.³³ Therefore, the effect of acute bouts of HIIE on hs-cTnT release can and should be investigated.

The purpose of this study was to investigate the effect of HIIE on hs-cTnT release and the relationship between hs-cTnT release and exercise HR, physical characteristics, and training information in the setting of the same relative exercise intensity (runs at hard and easy velocities).

2. Methods

2.1. Subjects

After approval of this study by the local Ethical Committee, 21 experienced marathon runners were recruited from the Department of Physical Education at a local university. They were free of diseases, did not smoke, and had not taken drugs or antioxidant supplements in the month before the study. Training history, volume, and personal best time in a marathon race (within 6 months) were self-reported. Table 1 summarises these physical characteristics and training information. An initial medical screening and examination were performed by a team of medical doctors and technicians. None of the subjects had a history of cardiac symptoms, and all had normal resting blood pressures and electrocardiographic results. All subjects provided their written consent and were fully informed about the purposes, procedures, and potential cardiovascular risks of this study.

2.2. Preliminary testing

All tests took place in a local sports science research centre between October and December at 14:00 and 18:00. Air conditions were similar for each test with small variations in temperature ($20.9 \pm 1.6^\circ\text{C}$) and humidity ($43.9\% \pm 9.5\%$). Subjects were asked to refrain from intense exercise and alcohol intake for 48 h before and after each test and were allowed to freely ingest pure water during

the test. Before the HIIE protocol, VO_{2max} (Max-II, Physio-Dyne Instrument Corp., Quogue, NY) and corresponding velocity of VO_{2max} (vVO_{2max}) for each subject were determined on a treadmill (Pulsar 4.0, h/p/cosmos sports & medical GmbH, Nussdorf-Traunstein, Germany) at a 2% slope. After a general warm up, the initial speed of $12 \text{ km}\cdot\text{h}^{-1}$ was increased by $1 \text{ km}\cdot\text{h}^{-1}$ every 3 min until the test subject's respiratory exchange ratio reached 1.00. The speed was then increased every 2 min by $1 \text{ km}\cdot\text{h}^{-1}$. The test was stopped either when the increase in VO_2 was less than $2.1 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ while the respiratory exchange ratio was 1.15 or greater, or when exhaustion was reached.³⁸ The VO_{2max} and maximal heart rate (HR_{max}) were the average of the highest value over 30 s, and the vVO_{2max} was the minimal speed at which VO_{2max} was reached, but only if this speed was sustained for at least 1 min.

2.3. Experimental trial

Each bout of HIIE consisted of a 2-min hard run at 90% vVO_{2max} followed by a 2-min easy run at 50% vVO_{2max} for recovery performed 23 times within 92 min.

2.4. Measurements

During HIIE, the subjects' HR (S810, Polar, Finland) was recorded before exercise in rest and during exercise every 2 min. Venous blood samples (5 ml) from the antecubital vein were collected before HIIE (pre), immediately after (0 h) and at 4 h and 24 h after exercise. The blood was allowed to clot at room temperature and was then centrifuged at 3000g for 15 min. The separated serum was then collected and stored at -80°C for further analysis.

The hs-cTnT analysis method is based on a new electrochemiluminescence technology that uses Elecsys 2010 automated batch analysers (Roche Diagnostics, Basel, Switzerland).³³ The measurement range was 3 to $1000 \text{ pg}\cdot\text{ml}^{-1}$. Data lower than the minimal detection limit was recorded as $3 \text{ pg}\cdot\text{ml}^{-1}$ when statistical analysis was conducted. The 99th percentile cut-off concentration and the level at the 10% coefficient of variation were 14 and $13 \text{ pg}\cdot\text{ml}^{-1}$, respectively, and the upper reference limit (URL) was set at $14 \text{ pg}\cdot\text{ml}^{-1}$.

2.5. Statistical analyses

Data are presented as means \pm standard deviations (SD) unless otherwise stated. Log-transformation was applied to the hs-cTnT values. A one-way repeated analysis of variance was used to determine the effect of time and identify the peak level of hs-cTnT across sampling points with *post hoc* Bonferroni tests when appropriate. The relationship between the increase of hs-cTnT at 4 h after exercise (delta scores of 4-h post- and pre-exercise values, $\Delta\text{hs-cTnT}_{4 \text{ h}}$) and the relevant variables, physical characteristics, training information and exercise HR and velocity were assessed by bivariate Pearson's product-moment correlation coefficients.

Depending on the magnitude of $\Delta\text{hs-cTnT}_{4 \text{ h}}$, the subjects were defined as a high responder ($n = 7$) with a large increase in 4-h hs-cTnT ($\Delta\text{hs-cTnT}_{4 \text{ h}}$: 32.0 to 95.0; 4-h hs-cTnT: 35.0 to $98.0 \text{ pg}\cdot\text{ml}^{-1}$), a medium responder ($n = 7$) with a moderate increase in 4-h hs-cTnT ($\Delta\text{hs-cTnT}_{4 \text{ h}}$: 15.1 to 31.9; 4-h hs-cTnT: 18.1 to $38.0 \text{ pg}\cdot\text{ml}^{-1}$) and a low responder ($n = 7$) with a small increase in 4-h hs-cTnT ($\Delta\text{hs-cTnT}_{4 \text{ h}}$: 0.3 to 13.0; 4-h hs-cTnT: 5.8 to $16.0 \text{ pg}\cdot\text{ml}^{-1}$). A mixed between-subjects and within-subject analysis of variance was conducted to explore the differences between the three groups in hs-cTnT and HR of hard and easy runs and average values, and a one-way between-groups analysis of variance was used to analyse the differences in subjects' physical characteristic, training information variables and percent of HR reserve (% HRR). The level of

Table 1

Relationship between high-sensitivity cardiac troponin T (hs-cTnT) and the subjects' physical characteristics, training information, and exercise heart rate (HR) during high-intensity interval exercise (HIIE).

		Δ hs-cTnT _{4h}	
		r	P
n	21 (20 males, 1 female)		
Age (y)	22.9 ± 4.5	-0.06	0.791
Body mass (kg)	64.2 ± 4.8	0.29	0.195
Body height (cm)	174.0 ± 6.2	-0.11	0.628
BMI (kg/m ²)	21.2 ± 1.3	0.54	0.011
VO _{2max} (ml·kg ⁻¹ ·min ⁻¹)	63.3 ± 5.6	-0.10	0.658
vVO _{2max} (km·h ⁻¹)	17.6 ± 1.4	-0.40	0.075
Velocity of hard run	15.8 ± 1.3	-0.40	0.075
Velocity of easy run	8.8 ± 0.7	-0.40	0.075
HR _{max} (beats·min ⁻¹)	191.5 ± 7.7	0.35	0.119
HR _{average} (beats·min ⁻¹)	157.8 ± 11.1	0.69	0.001
%HR _{max} (%)	82.4 ± 4.3	0.63	0.002
%HRR (%)	76.1 ± 5.8	0.779	0.000
HR _{hard run} (beats·min ⁻¹)	173.7 ± 9.8*	0.77	0.000
HR _{easy run} (beats·min ⁻¹)	141.8 ± 13.5*	0.58	0.006
Distance covered in HIIE (km)	18.9 ± 1.5	-0.32	0.161
Training history (years)	5.4 ± 2.9	-0.65	0.002
Training volume (km·w ⁻¹)	45.8 ± 17.2	-0.17	0.48
Personal best in a marathon event (min)	183.8 ± 15.2	0.68	0.016

BMI, body mass index; VO_{2max}, maximal oxygen consumption; vVO_{2max}, velocity of VO_{2max}; %HR_{max}, HR_{average}/HR_{max}; %HRR, percent of heart rate reserve; Δ hs-cTnT_{4h}, delta scores of 4-h post- and pre-exercise values, 0.3 to 95.0 pg·ml⁻¹; * HR_{average} is significantly different from the corresponding HR_{hard run} or HR_{easy run}; P < 0.05.

significance was set at 0.05. Statistical analysis was performed by IBM SPSS Statistics for Windows (v19.0; Armonk, NY).

3. Results

All 21 subjects completed the 92-min HIIE, and none of them reported any cardiac symptoms either during or within the 48-h post-exercise period. The exercise HR data are shown in Table 1, and the changes in hs-cTnT level after the completion of the 92-min HIIE are listed in Table 2. The level of hs-cTnT in all subjects was below the pre-exercise URL of 14 pg·ml⁻¹. It increased at 0 h (P < 0.000) and peaked at 4 h after exercise at a value significantly higher than that at 0 and 24 h after exercise (P < 0.000). The hs-cTnT level failed to return to the baseline value at 24 h after exercise (P = 0.006). In detail, the hs-cTnT level was still significantly elevated at 24 h after exercise in the high responder group (P = 0.002) but not in the medium (P = 0.5) and low (P = 1) responder groups. The hs-cTnT values of two subjects (15 and 18 pg·ml⁻¹) from the high responder group were still above the URL. Follow-up 48-h post-exercise blood sampling in these two subjects detected an hs-cTnT value in both of 10 pg·ml⁻¹, which was below the URL. The variation in the peak level of hs-cTnT after exercise was highly relevant to each subject's body mass index, training years, personal best completion time in a recent marathon, and exercise HR but not to running velocity during HIIE (Table 1 and Fig. 1).

There were no differences in vVO_{2max}, running velocities and

Table 2

High-sensitivity cardiac troponin T (hs-cTnT) measurements before and after high-intensity interval exercise (HIIE).

	Pre-exercise	0 h	4 h	24 h
Mean ± SD	4.7 ± 1.9	11.0 ± 4.6*‡	29.8 ± 22.0*	7.1 ± 3.7*‡
Median	5.0	10.0	25.6	6.6
Range	3.0 to 7.7	3.5 to 19.0	5.8 to 98.0	3.0 to 18.0
PR, %	0	28.6%	76.2%	9.5%

Values are in pg·ml⁻¹; n = 21; PR, positive rate, percentage of subjects with hs-cTnT exceeding the upper reference limit of 14 pg·ml⁻¹; * Significantly different from pre-exercise value; ‡ 4-h value significantly different from 0- or 24-h post-exercise value; P < 0.05.

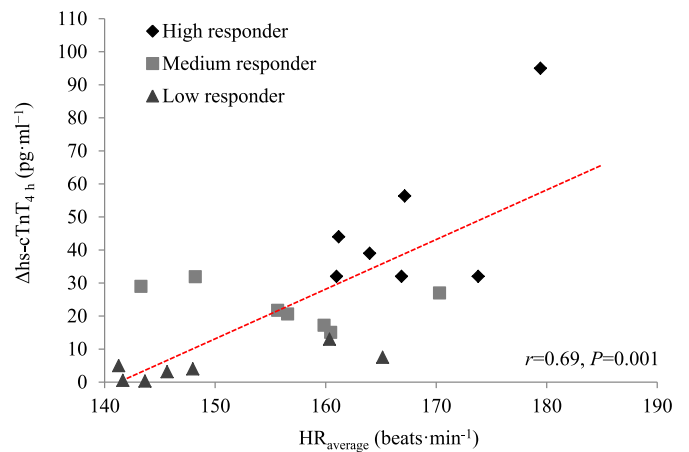


Fig. 1. Relationship between delta scores of 4-h post- and pre-exercise values of high-sensitivity cardiac troponin T (Δ hs-cTnT, pg·ml⁻¹) and average heart rate (HR_{average}, beats·min⁻¹) during high-intensity interval exercise (HIIE). High responder, subjects with large increase in 4-h hs-cTnT (Δ hs-cTnT_{4h}: 32.0 to 95.0; 4-h hs-cTnT: 35.0 to 98.0 pg·ml⁻¹; n = 7); medium responder, subjects with moderate increase in 4-h hs-cTnT (Δ hs-cTnT_{4h}: 15.1 to 31.9; 4-h hs-cTnT: 18.1 to 38.0 pg·ml⁻¹; n = 7); low responder, subjects with small increase in 4-h hs-cTnT (Δ hs-cTnT_{4h}: 0.3 to 13.0; 4-h hs-cTnT: 5.8 to 16.0 pg·ml⁻¹; n = 7).

distance run during HIIE between the high, medium and low responder groups (Table 3), but the hs-cTnT level (interaction effect of time × group: 0.000) (Fig. 2) and corresponding exercise HR (main effect: 0.000) (Fig. 3) were higher in the high responder group than those in the low responder group. Furthermore, there were significant differences in training years, training volume per week, personal best completion time in a recent marathon and % HRR between the high and low responders (Table 3).

4. Discussion

To our knowledge, this is the first study to explore the effect of HIIE on hs-cTnT release in a laboratory-based setting. Our findings suggest that one 92-min bout of HIIE, comprising 23 2-min periods

Table 3
Stratification of subjects' physical characteristics and training information according to the delta scores of 4-h post- and pre-exercise values of high-sensitivity cardiac troponin T (Δ hs-cTnT, $\text{pg}\cdot\text{ml}^{-1}$) after high-intensity interval exercise (HIIE).

	High responder	Medium responder	Low responder	<i>p</i>
n	7 (7 male)	7 (7 male)	7 (6 male, 1 female)	
Age (y)	21.3 \pm 2.1	24.1 \pm 6.7	23.3 \pm 3.7	0.498
Body mass (kg)	65.1 \pm 2.0	66.0 \pm 4.3	61.4 \pm 6.3	0.161
Body height (cm)	172.2 \pm 4.0	176.6 \pm 6.8	173.1 \pm 7.2	0.4
BMI (kg/m^2)	22.0 \pm 1.1	21.2 \pm 1.3	20.5 \pm 1.0	0.058
$\text{VO}_{2\text{max}}$ ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$)	61.8 \pm 6.3	62.7 \pm 6.6	65.5 \pm 3.4	0.451
$\text{vVO}_{2\text{max}}$ ($\text{km}\cdot\text{h}^{-1}$)	17.0 \pm 1.4	17.7 \pm 1.6	18.0 \pm 1.2	0.408
Velocity of hard run	15.3 \pm 1.3	15.9 \pm 1.4	16.2 \pm 1.0	0.408
Velocity of easy run	8.5 \pm 0.7	8.9 \pm 0.8	9.0 \pm 0.6	0.408
HR_{max} ($\text{beats}\cdot\text{min}^{-1}$)	197.0 \pm 4.8	187.4 \pm 7.1	190.1 \pm 8.9	0.057
% HRR (%)	71.0 \pm 5.0	77.1 \pm 3.9	80.1 \pm 4.7	0.005*
Distance in HIIE (km)	18.2 \pm 1.5	19.0 \pm 1.7	19.3 \pm 1.3	0.423
Training history (years)	3.0 \pm 1.8	5.0 \pm 1.6	7.9 \pm 2.9	0.003*
Training volume ($\text{km}\cdot\text{w}^{-1}$)	33.3 \pm 19.9	45.0 \pm 13.2	57.1 \pm 11.1	0.034*
Personal best (min)	193.3 \pm 6.5	191.3 \pm 20.5	171.6 \pm 8.5	0.043*

BMI, body mass index; $\text{VO}_{2\text{max}}$, maximal oxygen consumption; $\text{vVO}_{2\text{max}}$, velocity of $\text{VO}_{2\text{max}}$; % HRR, percent of heart rate reserve; high responder, subjects with large increase in 4-h hs-cTnT (Δ hs-cTnT_{4h}: 32.0 to 95.0; 4-h hs-cTnT: 35.0 to 98.0 $\text{pg}\cdot\text{ml}^{-1}$; n = 7); medium responder, subjects with moderate increase in 4-h hs-cTnT (Δ hs-cTnT_{4h}: 15.1 to 31.9; 4-h hs-cTnT: 18.1 to 38.0 $\text{pg}\cdot\text{ml}^{-1}$; n = 7); low responder, subjects with small increase in 4-h hs-cTnT (Δ hs-cTnT_{4h}: 0.3 to 13.0; 4-h hs-cTnT: 5.8 to 16.0 $\text{pg}\cdot\text{ml}^{-1}$; n = 7); * Significantly different between high and low responders; P < 0.05.

of exercise at 90% $\text{vVO}_{2\text{max}}$ interspersed with 2-min periods of exercise at 50% $\text{vVO}_{2\text{max}}$ for recovery, can elicit hs-cTnT elevation of nearly 634%, with 16 of 21 (76.2%) experienced marathon runners having an hs-cTnT value above the cutoff for the diagnosis of myocardial damage. High responders with a larger increase in hs-cTnT had a higher HR at the same absolute running velocity and relative exercise intensity (% $\text{vVO}_{2\text{max}}$) than the low responders. Exercise HR was positively related to the magnitude of the hs-cTnT response to exercise in the setting of fixed exercise intensity. Therefore, the novel finding of this study is that HR appears to be an important independent predictor of exercise-induced cTn release. Besides exercise HR, training adaptation may reduce the sensitivity of exercise-induced cTn release because the experienced marathon runners with longer training experience, higher training volume per week and better performance completed the HIIE with a lower average HR and correspondingly minor increase in hs-cTnT.

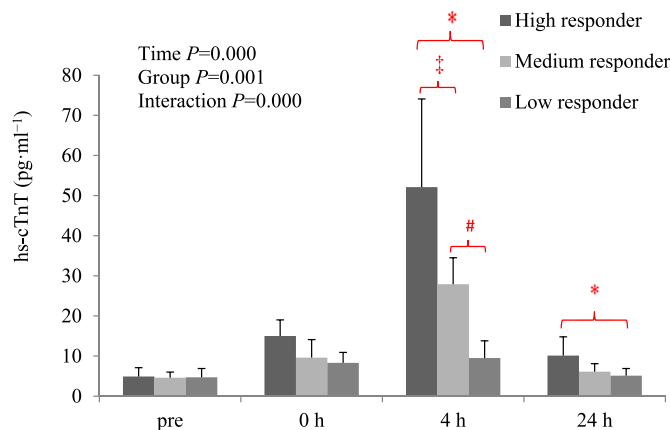


Fig. 2. Stratification of high-sensitivity cardiac troponin T (hs-cTnT, $\text{pg}\cdot\text{ml}^{-1}$) according to the delta scores of 4-h post- and pre-exercise values of hs-cTnT (Δ hs-cTnT, $\text{pg}\cdot\text{ml}^{-1}$). High responder, subjects with large increase in 4-h hs-cTnT (Δ hs-cTnT_{4h}: 32.0 to 95.0; 4-h hs-cTnT: 35.0 to 98.0 $\text{pg}\cdot\text{ml}^{-1}$; n = 7); medium responder, subjects with moderate increase in 4-h hs-cTnT (Δ hs-cTnT_{4h}: 15.1 to 31.9; 4-h hs-cTnT: 18.1 to 38.0 $\text{pg}\cdot\text{ml}^{-1}$; n = 7); low responder, subjects with small increase in 4-h hs-cTnT (Δ hs-cTnT_{4h}: 0.3 to 13.0; 4-h hs-cTnT: 5.8 to 16.0 $\text{pg}\cdot\text{ml}^{-1}$; n = 7); * Significantly different between high and low responders; # significantly different between medium and low responders; P < 0.05.

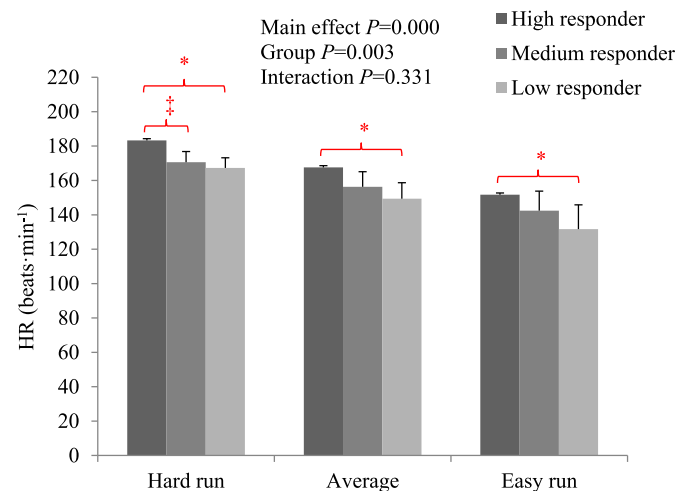


Fig. 3. Stratification of exercise heart rate (HR, $\text{beats}\cdot\text{min}^{-1}$) of hard and easy runs and the average during high-intensity interval exercise (HIIE) according to the delta scores of 4-h post- and pre-exercise values of hs-cTnT (Δ hs-cTnT, $\text{pg}\cdot\text{ml}^{-1}$). High responder, subjects with large increase in 4-h hs-cTnT (Δ hs-cTnT_{4h}: 32.0 to 95.0; 4-h hs-cTnT: 35.0 to 98.0 $\text{pg}\cdot\text{ml}^{-1}$; n = 7); medium responder, subjects with moderate increase in 4-h hs-cTnT (Δ hs-cTnT_{4h}: 15.1 to 31.9; 4-h hs-cTnT: 18.1 to 38.0 $\text{pg}\cdot\text{ml}^{-1}$; n = 7); low responder, subjects with small increase in 4-h hs-cTnT (Δ hs-cTnT_{4h}: 0.3 to 13.0; 4-h hs-cTnT: 5.8 to 16.0 $\text{pg}\cdot\text{ml}^{-1}$; n = 7); * Significantly different between high and low responders; † significantly different between high and medium responders; P < 0.05.

4.1. Effects of HIIE on hs-cTnT release

With respect to the inconsistent results of cTn release after interval exercise, the subjects, exercise protocol, sampling time and biomarkers chosen in our study may be different than those of past studies. Using a pre- and post-sampling method, George et al. showed that cTnT (3rd generation) was not present in 19 male soccer and rugby players after playing competitive games of 80 to 90 min.³⁰ Carranza-García et al. found that cTnT (3rd generation) was only detected in one (0.022 $\text{ng}\cdot\text{ml}^{-1}$) out of 21 adult soccer players after an 81 to 99-min match with average HR of 159 ± 20 $\text{beats}\cdot\text{min}^{-1}$.³¹ Nie et al. indicated that after a 66-min basketball game in adolescent players with an average HR (during intervals) of 169 ± 9 $\text{beats}\cdot\text{min}^{-1}$, multiple measurements of cTnT (3rd generation) in 4 of the 10 players were above the cutoff of $10\text{ pg}\cdot\text{ml}^{-1}$ for

myocardial injury.²⁷ The peak values of cTnT occurred at 4 h and returned to baseline within 24 h after exercise. Weippert et al. also showed that the hs-cTnT level at 4 h was higher than that at 1 h after a very short 21-min bout of HIIE and was above the URL in 5 of 13 (38.5%) adults.²⁹ It was suggested that the peak level of cTn appears within 3 to 4 h after either shorter-duration exercise,⁶ or longer-duration marathons.³⁴ This was also confirmed in our study with a positive rate of hs-cTnT elevation of 76.2%. A review paper²⁶ reported the increase of hs-cTnT to be 69.8% after running when evaluated immediately or within 6 h after exercise. When the 3rd-generation immunoassay of cTnT was adopted, it was reported that 47% of runners exceeded the detection limit in a meta-analysis.³⁴ The use of hs-cTnT measurement in exercise makes it clearer that cTn release after exercise commonly occurs in apparently 'healthy athletes', and hs-cTnT has higher precision at measured concentrations below 100 pg·ml⁻¹,³³ which is exactly the general range of exercise-induced cTn release. In our study, hs-cTnT rapidly decreased 24 h after exercise and returned to a normal value in all subjects within 48 h even with a strenuous exercise protocol. Exercise HR is related to the changes of hs-cTnT. This suggests that exercise-induced cTn release may be a physiological process directly related to cardiac workload rather than pathological process. Actually, it is assumed that increased membrane permeability or bleb formation may be involved in this transient release of cytosolic cTn in cardiomyocytes.^{4,35} Our previous research also partially confirmed the hypothesis that peak cTn was related to the concentration of malondialdehyde (MDA), which is a marker of lipid peroxidation and cell membrane permeability.³⁶ In this study, hs-cTnT rapidly decreased but failed to return to baseline at 24 h after exercise, which challenges the common point of view that 24 h is adequate for recovery.^{3,6} The novel observation of our study was that delayed recovery occurred in the high responder group, which had higher peak hs-cTnT values and exercise HR during HIIE. Scherr et al. also reported that 72-h levels of hs-cTnT in adults were higher than baseline levels after a marathon.³⁷ HIIE is a popular training method used by long distance runners especially in training programmes during the competition season.³⁹ This suggests that further study should be performed to evaluate the effect of repeated HIIE training sessions on hs-cTnT release, and its possible relationship to overtraining.

4.2. Potential factors regarding the variation of hs-cTnT release after HIIE

Reproducibility in the release of hs-cTnT after constant³⁹ and interval²⁸ exercise was reported and was influenced by certain factors. Exercise intensity, duration, training experience, age and weight are reported to affect exercise-induced cTn release.^{4,34} Because many studies were conducted in field-based settings during which running velocity was self-selected, the influencing factors could not be manipulated. Two laboratory-based studies confirmed that exercise intensity strongly affected exercise-induced cTn release,^{12,13} and such release would be severe as exercise duration increased.^{14,16} We fixed the relative exercise intensity and found high and low responders with similar values of VO_{2max}, HR_{max} and running velocity and distance but different exercise HRs and variations of cTn release. The low responder group had better training, as indicated by longer training experience and volume per week and a better personal best in an event, and completed HIIE at a lower average HR and % HRR than the high responders. These observations suggest that the reduction in exercise HR with training¹⁹ may have a significant positive impact on cTn release during exercise. Taken together, these factors suggest that HR during exercise may be a good single predictor of hs-cTnT. Exercise-induced cTn release is the cardiac response to exercise

stress in a single bout of exercise. Actually, cTnT elevation is primarily dependent on HR when tachycardia is present without any coronary disease evident at rest.¹⁸ Kim et al. examined exercise status and found that the cTnI level after a marathon was related to increased blood pressure, which is another parameter affecting the workload of the heart.⁴⁰ Further study should consider to correct for HR and exercise intensity when constructing impact factors contributing to exercise-induced cTn release. The limitations of this study are the lack of data on stroke volume and cardiac function and that the effects of exercise duration were not considered. The low responder group contained two subjects with hs-cTnT levels slightly higher (15.2 and 16.0 pg·ml⁻¹) than the URL of 14 pg·ml⁻¹. Further study should consider conducting 'dose-response' research to investigate the determinates of cardiac work in exercise-induced cTn release, and also a longitudinal study is recommended.

5. Conclusion

A single bout of HIIE performed in 23 2-min periods at 90% vVO_{2max} interspersed with 2-min periods at 50% vVO_{2max} for recovery, can elicit hs-cTnT elevation of nearly 634%. Considering all of the affecting factors, it appears that HR is a good predictor of exercise-induced cTn release under fixed exercise intensity and that exercise-induced cTn release is directly related to cardiac work.

Conflicts of interest

The authors have no financial conflicts.

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Authorship

Each author's contribution to the manuscript is equal.

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