Acute Effects of Heart Rate Variability Biofeedback on H-reflex and Maximal Voluntary Isometric Strength

Jeffrey Pagaduan (jeffrey.pagaduan@utas.edu.au)
University of Tasmania Launceston Campus https://orcid.org/0000-0003-1435-7636
Sam SX Wu
Swinburne University of Technology
James W. Fell
University of Tasmania - Launceston Campus
Yung-Sheng Chen
University of Taipei

Research

Keywords: muscle strength, biofeedback, resonance frequency breathing, muscle function

Posted Date: February 21st, 2020

DOI: https://doi.org/10.21203/rs.2.24159/v1

Abstract

Background Heart rate variability biofeedback (HRV BFB) is a visually-guided paced breathing scheme that stimulates resonance in the cardiovascular system. Up to date, the influence of HRV BFB on neuromuscular function remains unknown. The purpose of this study was to investigate the effects of a single-session HRV BFB on Hoffman reflex (H-reflex) of the soleus muscle and maximal voluntary isometric contraction (MVC) of plantar flexors.

Methods Eleven male healthy participants (height: 173.6 ± 7.5 cm; weight: 74.5 ± 17.3 kg; age: 24.6 ± 4.8 yrs) volunteered to undergo a randomized-crossover intervention involving a 10-minute HRV BFB and normal breathing (CON), separated by 48-hours. Pre and post indices for H-reflex, and post-only MVC in HRV BFB were evaluated using two-way repeated measures ANOVA and independent T-test respectively.

Results No significant differences in H-reflex markers between HRV BFB and CON were found. Both groups posted non-significant difference in MVC.

Conclusion An acute HRV BFB was not sufficient in eliciting significant changes in motoneuron excitability of the soleus muscle and maximal muscle strength of plantar flexors.

Background

Heart rate variability biofeedback (HRV BFB) is a non-invasive, visually-guided paced breathing intervention believed to improve psychophysiological indices [1–3]. HRV BFB utilizes a breathing pace (0.075–0.12 Hz or 4.5–7.2 breaths/min), also known as resonance frequency (RF), that generates rhythmical changes in the baroreflex and activates the resonant properties in the cardiovascular [4–7]. The baroreflex plays a crucial role in the regulation of blood pressure that operates in a negative feedback loop, such that increasing blood pressure reduces heat rate and vice versa. Key features in HRV BFB include occurrence of maximal heart rate oscillations, and simultaneous oscillations of heart rate and respiration. Regular HRV BFB practice enhances baroreceptor activity, vagal afferents and efferents that facilitate improvement in health outcomes [1, 4, 8–11].

Recently, the application of HRV BFB has been extended to neuromuscular application and skill acquisition. For example, Gruzelier et al. [8] demonstrated that HRV BFB enhanced the technique and artistry of dancers. Paul and Garg [10] posted improvement in shooting, dribbling, and passing among basketball athletes after HRV BFB. Similarly, Paul et al. [12] recorded enhancement in shooting ability of basketball athletes after HRV BFB. However, the existing mechanism in HRV BFB in relation to neuromuscular events is unknown.

To the researchers' knowledge, no previous study has investigated the influence of HRV BFB or any paced breathing technique on neuromuscular responses. An enhancement in baroreflex with HRV BFB might positively influence activity in the central autonomic network and facilitate improvement in neural excitability [1, 13–20]. Accordingly, neural excitability of the alpha motoneural pool could be revealed by the determination of the Hoffman reflex (H-reflex), a monosynaptic reflex in the spinal cord [21–25]. Thus, the primary purpose of this study was to determine motoneural excitability after HRV BFB utilizing the activity of H-reflex. In another light, if central autonomic network is associated with alpha motoneural pool, HRV BFB may improve the muscle-brain communication pathway and increase voluntary muscle contraction independent from H-reflex [26, 27]. However, there is no study that examined influence of HRV BFB on voluntary muscle strength. Hence, the secondary purpose of this study was to identify the effect of HRV BFB on maximal isometric strength of the plantar flexors.

Methods

Participants

Eleven healthy males (height: 173.6 ± 7.53 cm; weight: 74.5 ± 17.3 kg; age: 24.6 ± 4.76 y) with no reported lower body injury 2 months prior to experimentation were recruited by YSC for this pilot study. Participants were asked to avoid any strenuous physical activity and caffeine containing food/beverage 24 hours prior to experimentation. Last meal intake was at least 2 hours before testing. Sample size in this pilot study was based on the study of Oza and colleagues [28]. A written informed consent was collected before any further experimentation. Ethical clearance for this study was obtained from the University of Tasmania Human Research Ethics Committee (H0016508), in agreement with the University of Taipei.

Procedures

The participants attended three experimentation sessions, separated by 48 h, at the Exercise Performance Laboratory of University of Taipei. Measurement of anthropometrics (height and weight), identification of RF, and familiarization of MVC protocol were administered in the first session. In the second session, a randomized 10 min HRV BFB or CON was facilitated. Randomization was carried out by JCP using an online random allocation tool [29]. Upon arrival at the testing facility, an electrode attachment to the soleus muscle (SOL) for surface electromyography (EMG) and stimulation electrodes on popliteal fossa and over the patella of the right limb were applied. This was followed by pre-testing for H-reflex. Subsequently, the participants performed HRV BFB/CON with knee angle set at approximately 90-120 degrees. HRV BFB was carried out using a commercial HRV BFB equipment (HRV Starter System, Thought Technology, Canada). Participants under CON seated quietly and performed normal breathing for 10 min while asked to gaze at the computer screen. HRV BFB/CON was succeeded by post H-reflex test. Then, participants performed MVC testing. A crossover intervention was performed on Day 3. Figure 1 displays the experimental protocol for this study.

Resonance frequency

An elastic belt and finger sensor were placed on the participant to allow simultaneous recording of respiration and heart rate (HRV Starter System, Thought Technology, Canada). Then, a 5-minute familiarization of diaphragmatic breathing with visual feedback occurred. This was followed by RF testing that involves two-minute breathing at various frequencies (6.5, 6.0, 5.5, 5.0, 4.5 times per min). RF is established as the breathing pace that displayed the highest amplitude in the low frequency of HRV [5, 30].

H –reflex

H-reflex was measured from the soleus (SOL) electromyography (EMG). A surface electrode (TSD150A, Biopac Systems, USA) was placed 2/3 from the medial condyles of the femur to the medial malleolus and central position in the medial-lateral direction of the border of SOL. In addition, a reference electrode was attached on the right hand of the participants. Further, an adhesive electrode (10 x 10 mm, FA 25, Gem-Stick, Australia) was placed on the right popliteal fossa as cathode and another (50 x 50 mm, Life Care, Taiwan) adhesive electrode was fixed over the right patella as the anode. After, participants were asked to seat with right knee extended at approximately 180 degrees, while the left knee flexed at 90-120 degrees. Hip flexion was 90-120 degrees. Recording of EMG signals were acquired using a commercial data acquisition system (MP150, Biopac Systems, USA) filtered with a band-pass range of 10-500 Hz and amplified with a gain of 1,000 times. The common mode rejection ratio for the EMG amplifier was 100dB. Sampling rate was set to 2.5 kHz. A single electrical impulse was applied to the right posterior tibial nerve via an electrical stimulator (DSH7, Digitimer, Herfordshire, UK) with 1000μs pulse duration to identify SOL H-reflex response. To determine maximal levels of H-wave and M-wave, stimulation intensity was increased with 10 mA increments until maximum M-wave (Mmax) was identified. The stimulation intensity for exhibiting maximum H-wave (Hmax) was determined by using 2 mA increment when the H-reflex threshold was identified (see Figure 2). To record the H-reflex responses for comparison, stimulation intensity was controlled to elicit an H-reflex response with a small incidence of M wave at 10% to 20% Mmax [31]. Each stimulation intensity was applied four times with 10 s inter stimulation interval. A commercial data acquisition system (Acqknowledge 4.2.1 software, Biopac Inc., USA) with custom-written program was used to synchronize the electrical stimulation trigger and EMG recording. H-reflex parameters that were utilised for analysis included M wave at maximal H-reflex (M wave at Hmax), Hmax, maximal M-reflex response (Mmax), Hmax/Mmax ratio (maximal Hmax response to normalized Mmax), and M wave at Hmax/Mmax ratio (M wave during Hmax normalized to maximal M-reflex response). Hmax estimates the number of activated Ia afferents elicited by electrical stimulations [22, 23]. Mmax represents the entire activation of descending inputs to motor axons [24, 30, 31]. Hmax/Mmax ratio is the proportion of the entire motoneuron pool capable of being recruited by Ia afferents [24, 32]. M wave at Hmax refers to the proportion of motor fibers activated by electrical stimulations [23, 31]. During H-reflex testing, participants were encouraged to breathe normally. A sample of H wave and M wave recruitment curves from one representative participant is displayed on Figure 2.

Maximal voluntary isometric contraction

An isokinetic dynamometer (Biodex System 4, Shirley, New York) was utilized to measure MVC of plantar flexors. In this test, participants performed three x 3-second plantar flexor MVC. Prior to MVC testing, the participants performed plantarflexion-dorsiflexion at force intensity of submaximal level as warm-up for

30 times, followed by a 4-minute rest. A visual feedback of torque production via a computer monitor located in front of the participant, and standardized verbal encouragement were provided to facilitate maximal effort during each trial. Rest interval between trials was one-minute. The highest MVC torque value was recorded for analysis.

Statistical Analyses

Data are expressed as mean ± standard deviation. Normality of data was analysed using Kolmogorov-Smirnov method. A 2 x 2 repeated measures ANOVA was employed to analyse any significant main effects (condition and time) and interaction (condition x time). Effect size was estimated using eta squared. Paired T-test was carried out for any significant parameter main effect. The same method was also used to establish any difference in MVC between HRV BFB and CON. Statistical procedures were carried out using a commercial statistical package (SPSS ver 22, IBM Corp, USA). Significance was set at alpha of 0.05.

Results

Kolmogorov-Smirnov test confirmed data normality. RF of participants ranged from 4.4 to 7.4 breaths per minute (0.09 ± 0.02 Hz).

H-Reflex

Two-way repeated measures ANOVA revealed non-significant main effect of condition on Hmax/Mmax ratio at $F(1,10) = 0.064$, $p > 0.05$, $\eta^2 = 0.805$. The interaction of condition and time on Hmax/Mmax ratio was non-significant at $F(1,10) = 2.364$, $p > 0.05$, $\eta^2 = 0.191$. There was a significant main effect of time on Hmax/Mmax ratio at $F(1,10) = 0.580$, $p = 0.040$, $\eta^2 = 0.358$. Subsequent paired T-test indicated that Hmax/Mmax ratio significantly decreased after HRV BFB at $t(10) = 3.130$, $p = 0.011$. On the other hand, there was no significant change in Hmax/Mmax after CON at $t(10) = 2.324$, $p = 0.423$.

The main effect of condition on M wave at Hmax was non-significant at $F(1,10) = 2.297$, $p > 0.05$, $\eta^2 = 0.187$. The main effect of time on M wave at Hmax was also non-significant at $F(1,10) = 1.792$, $p > 0.05$, $\eta^2 = 0.150$. No significant interaction between condition and time was seen on M wave at Hmax at $F(1,10) = 1.233$, $p > 0.05$, $\eta^2 = 0.110$. Condition was not a significant main effect on Hmax at $F(1,10) = 0.020$, $p > 0.05$, $\eta^2 = 0.002$. Similarly, there was no significant main effect of time Hmax [$F(1,10) = 2.561$, $p > 0.05$, $\eta^2 = 0.204$]. There was no significant main interaction of condition and time on Hmax at $F(1,10) = 1.151$, $p > 0.05$, $\eta^2 = 0.301$.

No significant main effect of condition for Mmax was identified at $F(1,10) = 0.230$, $p > 0.05$, $\eta^2 = 0.022$. There was also non-significant main effect of time on Mmax at $F(1,10) = 0.645$, $p > 0.05$, $\eta^2 = 0.061$. The interaction of condition and time on Mmax was not significant at $F(1,10) = 0.000$, $p > 0.05$, $\eta^2 = 0.000$. Condition as a main effect on M wave at Hmax/Mmax was non-significant at $F(1,10) = 2.313$, $p < 0.05$, η^2

= 0.188. Additionally, there was no significant main effect of time on M wave at Hmax/Mmax at $F(1,10) = 0.565$, $p < 0.05$, $\eta^2 = 0.053$. Non-significant interaction between condition and time was seen on M wave at Hmax/Mmax at $F(1,10) = 0.712$, $p > 0.05$, $\eta^2 = 0.066$.

MVC

The difference in MVC between HRV BFB and CON was not significant at $t(10) = -1.045$, $p = 0.321$. Table 1 displays the H-reflex parameters and MVC with HRV BFB and CON.

Table 1
H-reflex variables and MVC in HRV BFB and CON.

	HRV BFB		**CON**	
	Pre	Post	Pre	Post
M wave at Hmax (mV)	0.33 ± 0.13	0.33 ± 0.16	0.63 ± 0.63	0.53 ± 0.45
Hmax (mV)	1.75 ± 0.75	1.78 ± 0.75	1.71 ± 0.71	1.61 ± 0.91
Mmax (mV)	3.16 ± 0.76	3.11 ± 0.89	3.23 ± 1.04	3.18 ± 1.04
Hmax/Mmax ratio	0.56 ± 0.15	0.50 ± 0.19*	0.54 ± 0.16	0.54 ± 0.16
M wave at Hmax/Mmax ratio	0.11 ± 0.04	0.11 ± 0.05	0.19 ± 0.17	0.17 ± 0.14
MVC (N m)		104.5 ± 39.03		109.9 ± 34.57

Note: * - significant at 0.05 level between pre and post comparison; M at Hmax – M wave at Hmax; Hmax – maximal H-reflex response; Mmax – maximal M-reflex response; Hmax/Mmax ratio – maximal H-reflex response normalized to M-reflex response; M wave at Hmax/Hmax ratio - M wave during Hmax normalized to maximal M-reflex response; MVC – maximal voluntary isometric contraction.

Discussion

This is a novel study examining the effect of an acute HRV BFB on the neural pathway using the H-reflex of the soleus. Change of H-reflex amplitude reflects the inhibitory and excitatory neural activation of alpha motoneuronal pool [27]. Results revealed no significant difference in M wave at Hmax between HRV BFB and CON. Non-significant difference in Hmax was also found in both schemes. Similarly, Mmax was not significantly different between HRV BFB and CON. The difference in Hmax/Mmax ratio from HRV BFB and CON was non-significant. M wave at Hmax/Mmax ratio were not significant different among conditions.

The non-significant findings in H-reflex properties between the HRV BFB and CON can be attributed to different factors. Firstly, the mechanical variables (e.g. duration) in the single-session HRV BFB may not be sufficient in altering H-reflex properties. Second, researchers observed notable intraindividual and interindividual variability. These can be addressed by increasing the sample size and employment of additional H-reflex measurements. Future studies in HRV BFB and H-reflex should warrant the consideration of the aforementioned factors that might influence the outcomes.

An interesting finding in this pilot study showed decreased Hmax/Mmax ratio after HRV BFB. Although not significantly different with CON, this finding may reflect increased presynaptic inhibition from primary afferent depolarisation [25, 27, 32]. Presynaptic inhibition is a primary neural mechanism to regulate the H-reflex modulation. It seems that a single HRV BFB intervention session may have reduced the motoneural pool excitability between Ia afferents and alpha motor neurons. The neural inputs at the presynaptic level inhibits neurotransmitters releasing to Ia afferent terminals and is related to HRV BFB intervention [29]. However, the exact mechanisms to influence of neural transmission via HRV BFB was unclear in our study. The reduced Hmax/Max ratio after HRV BFB in this study may be connected to stress-reduction capacity of HRV BFB. This is partially supported by the study of Bagheri et al. [33] which exhibited lower Hmax/Mmax ratio in low-stressed athletes compared to high-stressed athletes. Thus, the decreased Hmax/Mmax ratio after HRV BFB in this study indicates a promising ergogenic effect of HRV BFB.

The secondary purpose of this study was to determine the maximal isometric strength of plantar flexors after HRV BFB and CON. It was discovered that no difference in MVC existed after HRV BFB and CON. This means that both conditions exhibited similar muscle force production [34]. Possible factors that led to the outcomes can be linked to variability in interindividual responses to HRV BFB and CON. It may also be possible that a single-session HRV BFB was not sufficient in improving muscle force mechanics. Thus, long-term studies in HRV BFB and MVC should be administered to elucidate information on possible muscle force capability adaptations with HRV BFB.

Conclusion

In conclusion, a single session HRV BFB does not influence the enhancement of motoneural excitability of the soleus muscle and muscle force output of plantar flexors in healthy males.

Limitations

This novel study serves as an impetus for future research within the context of HRV BFB, or any paced breathing method and neuromuscular function. However, there are limitations that should be noted. First, generalizability of results in this study should be avoided as the outcomes are only applicable to the sample population involved. Also, H-reflex testing entails vigorous procedure, thus it was prudent to use a small sample size for this demonstration. Lastly, this study was administered in an acute session. Long-term HRV BFB may facilitate plausible results in musculoskeletal performance that warrant the merit of HRV BFB.

Declarations

Acknowledgements

The authors would like to thank all the individuals who volunteered in this study.

Author's contributions

Conception and design of the study: JCP, YSC, SSW, JWF. Acquisition of data or analysis and interpretation of data: JCP, YSC. Drafting the article or revising it critically for important intellectual content: JCP, YSC, SSW. All authors read and approved the final Manuscript.

Funding

No funding was received for this study.

Availability of data and materials

The datasets generated and/or analysed during the current study are not publicly available. However, data are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

This study was approved by University of Tasmania Human Research Ethics Committee (H0016508), in agreement with the University of Taipei.

Consent for publication

Obtained.

Competing interests

The authors declare they have no competing interests.

Author details

[1] College of Health and Medicine, School of Health Sciences, University of Tasmania,

Newnham, Tasmania. [2] School of Health Sciences, Faculty of Health, Arts, and Design, Swinburne University, Victoria, Australia. [3] Department of Exercise and Health Sciences, University of Taipei, 1 Ai-Guo West Road, Taipei, Taiwan.

References

1. Gevirtz R. The promise of heart rate variability biofeedback: evidence-based applications. Biofeedback. 2013;41:110-120.
2. Lehrer PM, Gevirtz R. Heart rate variability biofeedback: how and why does it work? Front Psych. 2014;5:756.
3. Reiner R. Integrating a portable biofeedback device into clinical practice for patients with anxiety disorders: results of a pilot study. Appl Psychophysiol Biofeedback. 2008;33(1):55-61.
4. Lehrer P, Eddie D. Dynamic processes in regulation and some implications for biofeedback and biobehavioral interventions. Appl Psychophysiol Biofeedback. 2013; 38(2):143-155.
5. Lehrer PM,Vaschillo E, Vaschillo B. Resonant frequency biofeedback training to increase cardiac variability: rationale and manual for training. Appl Psychophysiol Biofeedback. 2000;25(3):177-191.
6. Vaschillo EG, Vaschillo B, Lehrer PM. Characteristics of resonance in heart rate variability stimulated by biofeedback. Appl Psychophysiol Biofeedback. 2006;31(2):129-142
7. Vaschillo E, Lehrer P, Rishe N, Konstantinov M. Heart rate variability biofeedback as a method for assessing baroreflex function: a preliminary study of resonance in the cardiovascular system. Appl Psychophysiology and Biofeedback. 2002;27(1):1-27.
8. Gruzelier JH, Thompson T, Redding E, Brandt R, Steffert T. Application of alpha/theta neurofeedback and heart rate variability training to young contemporary dancers: state anxiety and creativity. Int J Psychophysiol. 2014;93(1):105-111.
9. McCraty R, Shaffer F. Heart rate variability: new perspectives on physiological mechanisms, assessment of self-regulatory capacity, and health risk. Glob Advan Health Med. 2015;4(1):46-61.
10. Paul M, Garg K. The effect of heart rate variability biofeedback on performance psychology of basketball players. Appl Psychophysiol Biofeedback. 2012;37(2):31-144.
11. Russo MA, Santarelli D, O'Rourke D. The physiological effects of slow breath in healthy human. Breathe. 2017;13(4):298-309.
12. Paul M, Garg K, Sandhu JS. Role of biofeedback in optimizing psychomotor performance. Asian J Sport Med. 2012;3(1):29-40.
13. Beissner F, Meissner K, Bär KJ, Napadow V. The autonomic brain: an activation likelihood estimation meta-analysis for central processing of autonomic function. J Neurosci. 2013;33(25):10503-10511.
14. Bennaroch EE. The central autonomic network: functional organization, dysfunction, and perspective. Mayo Clin Proc. 1993;68(10):988-1001.
15. Eckberg DL, Eckberg MJ. Human sinus node responses to repetitive, ramped carotid baroreceptor stimuli. Am J Physiol. 1982;242(4):H638-H644.
16. Huang C, Gevirtz RN, Onton J, Criado JR. Investigation of vagal afferent functioning using the heartbeat event related potential. Int J Psychophysiol. 2018;131:113-123.
17. Mackinnon S, Gevirtz R, McCraty R, Brown M. Utilizing heartbeat evoked potentials to identify cardiac regulation of vagal afferents during emotion and resonant breathing. Appl Psychophysiol Biofeedback. 2013;38(4):241-255.

18. Park G, Thayer JF. From the heart to the mind: cardiac vagal tone modulates top-down and bottom-up visual perception and attention to emotional stimuli. Front Psych. 2014;5:278.
19. Skrelov M, Dayan E, Browner N. Functional neuroimaging of the central autonomic network: recent developments and clinical implications. Clin Auton Res. 2019;29(6):555-566.
20. Thayer JF, Lane RD. A model of neurovisceral integration in emotional regulation and dysregulation. J Affect Disord. 2000;61(3):201-216.
21. Chen YS, Crowley Z, Zhou S, Cartwright C. Effects of 12-week Tai Chi training on soleus H-reflex and muscle strength in older adults: a pilot study. Eur J Appl Physiol. 2012;112(6):2263-2268.
22. Gajewski J, Mazur-Różycka J. The H-reflex as an important indicator in kinesiology. Hum Mov. 2016;17(2):64-71.
23. Knikou M. The H-reflex as a probe: Pathways and pitfalls. J Neurosci Methods. 2008; 171(1):1-12.
24. Palmieri RM, Ingersoll CD, Hoffman MA. The Hoffman reflex: Methodologic considerations and applications for use in sports medicine and athletic training. J Athl Train. 2004;39(3):268-277.
25. Pierrot-Desiglligny E, Mazevet D. The monosynaptic reflex: a tool to investigate motor control in humans. interest and limits. Neurophysiol Clin. 2000;30(2):67-80.
26. Hodgson MJ, Docherty D, Zehr EP. Postactivation potentiation of force is independent of h-reflex excitability. Int J Sports Physiol Perform. 2008;3(2):219-231.
27. Zehr EP. Considerations for use of the Hoffman reflex in exercise studies. Eur J Appl Physiol. 2002;86(6):455-468.
28. Oza PD, Dudley-Javoroski S, Shields RK. Modulation of H-reflex depression with paired-pulse stimulation in healthy active humans. Rehabil Res Pract 2017;2017:5107097
29. Urbaniak GC, Plous S. Research Randomizer (version 4.0). 2015. https://www.randomizer.org
Task Force of the European Society of Cardiology and North American Society of Pacing and Electrophysiology. Heart rate variability: standards of measurement, physiological interpretation, and clinical use. Circulation. 1996;93(5):1043-1065.
30. Chen YS, Zhou S. Soleus H-reflex and its relation to static postural control. Gait Posture. 2011;33(2):169-178.
31. Chen YS, Zhou S, Cartwright C. Modulation of soleus H-reflex during shortening and lengthening muscle actions in young and older adults. Chin J Physiol. 2015;58(1): 9-18.
32. Kipp K, Johnson ST, Hoffman MA. Functional principal component analysis of H-reflex recruitment curves. J Neurosci Methods. 2011;197(2):270-273.
33. Bagheri R, Pourahmadi MR, Hedeyati R, Safavi-Farokhi Z, Aminian-Far A, Tavakoli S, Bagheri J. Relationships between Hoffman reflex parameters, trait stress, and athletic performance. Percept Mot Skills. 2018;125(4):749-768.
34. Kuo IY, Ehrlich BE. Signaling in muscle contraction. Cold Spring Harb Perspect Biol. 2015;7:a006023.

Figures

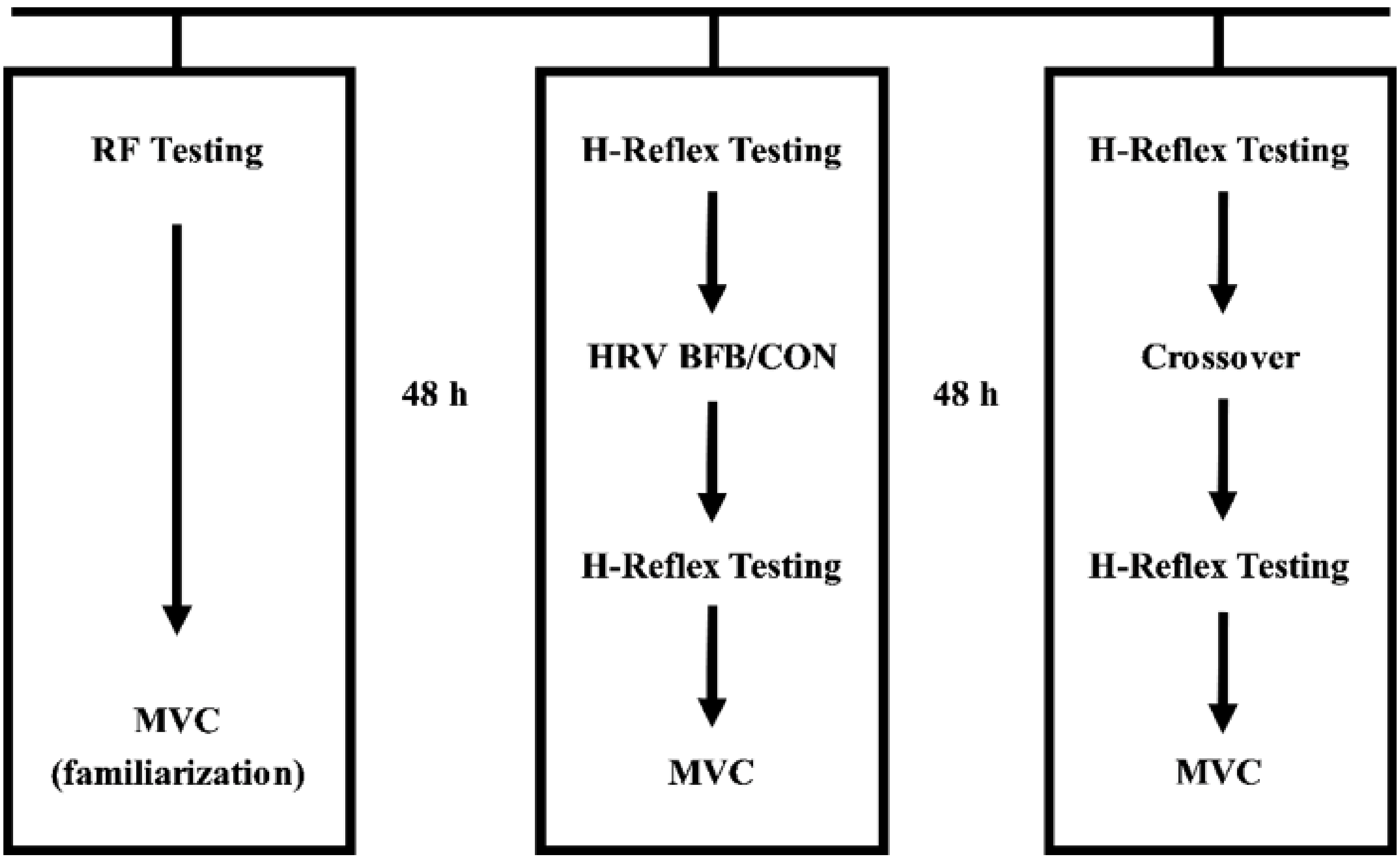

Figure 1

Experimental protocol

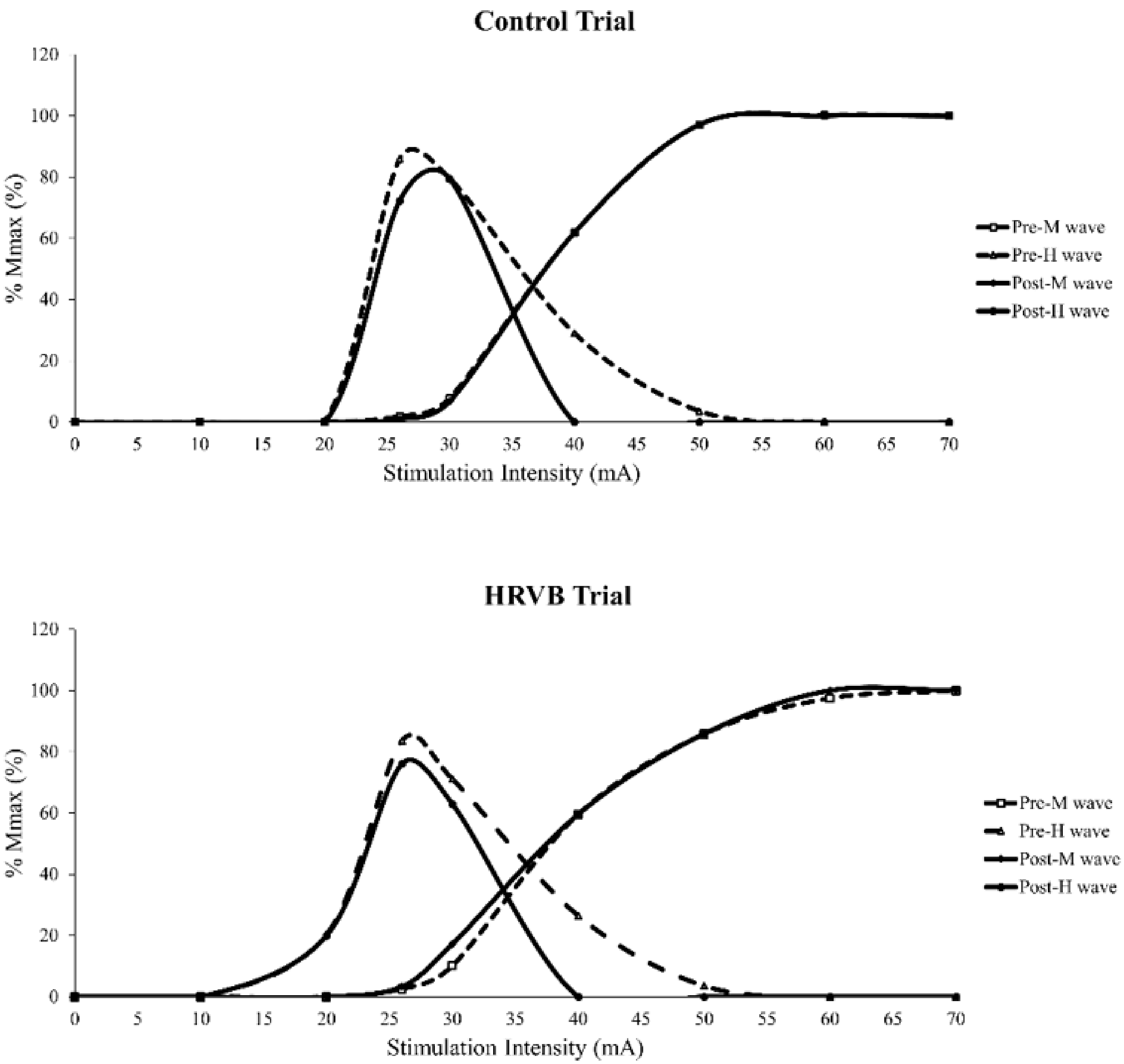

Figure 2

Sample of H-wave and M-wave curves

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- CONSORTChecklist.doc