



Effect of portable non-invasive ventilation & environmental conditions on everyday activities

Bajema, Anna; Swinbourne, Anne K; Gray, Marion; et.al.

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Bajema, Swinbourne, A. K., Gray, M., & Leicht, A. S. (2017). Effect of portable non-invasive ventilation & environmental conditions on everyday activities. *Respiratory Physiology & Neurobiology*, 243, 55–59.

<https://doi.org/10.1016/j.resp.2017.05.009>

Document Type: Accepted Version

Link to Published Version: <https://doi.org/10.1016/j.resp.2017.05.009>

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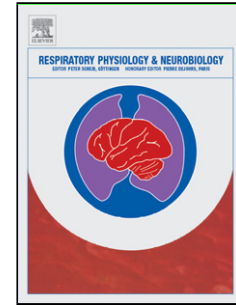
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Title: Effect of portable non-invasive ventilation and environmental conditions on everyday activities

Authors: Anna Bajema, Anne L. Swinbourne, Marion Gray, Anthony S. Leicht



PII: S1569-9048(17)30098-8
DOI: <http://dx.doi.org/doi:10.1016/j.resp.2017.05.009>
Reference: RESPNB 2815

To appear in: *Respiratory Physiology & Neurobiology*

Received date: 28-3-2017
Revised date: 19-5-2017
Accepted date: 24-5-2017

Please cite this article as: Bajema, Anna, Swinbourne, Anne L., Gray, Marion, Leicht, Anthony S., Effect of portable non-invasive ventilation and environmental conditions on everyday activities. *Respiratory Physiology and Neurobiology* <http://dx.doi.org/10.1016/j.resp.2017.05.009>

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Effect of portable non-invasive ventilation & environmental conditions on everyday activities

Anna Bajema^a, Anne L. Swinbourne^a, Marion Gray^b and Anthony S. Leicht^c

^a*Psychology, James Cook University, Townsville, AUSTRALIA*

^b*Cluster for Health Improvement, University of the Sunshine Coast, Sippy Downs, AUSTRALIA*

^c*Sport and Exercise Science, James Cook University, Townsville, AUSTRALIA*

Corresponding author: Associate Professor Anthony Leicht, Sport and Exercise Science, James Cook University, Townsville, Queensland, 4811, Australia, Phone: +61 7 47814576, E-mail: Anthony.Lleicht@jcu.edu.au

Total word count:	2,786 words (excluding abstract, references, tables, figures, acknowledgements, etc)
Abstract word count:	157 words
Number of references:	18
Number of tables:	3
Number of figures:	1

Highlights

- Tropical conditions and NIV use had little impact on responses during daily tasks
- Increased task intensity may enhance the effects of NIV use with healthy adults
- Population, intensity, environment and NIV use may impact on adults daily living

Abstract

The current study examined the effect of non-invasive ventilation (NIV) within environments of differing temperature and humidity on several physiological and perceptual responses while performing six activities of daily living (i.e. putting on shirt/shoes/trousers, vacuuming, hanging towels, and walking on a treadmill). Sixteen healthy participants completed the activities of varying difficulty within four experimental conditions: with and without NIV; and in temperate (22°C, 40% relative humidity) and hot-humid environments (32°C, 70% relative humidity). Comparisons of physiological responses between conditions were examined via repeated measures ANOVAs. Overall, NIV resulted in similar physiological and perceptual responses within all environmental conditions for healthy participants. Further, NIV use increased heart rate during the most strenuous task (29.5 ± 12.7 vs. 22.8 ± 12.0 bpm, $p=0.008$) indicating NIV use may stress cardiovascular functioning during moderate-high intensity activities. Tropical conditions did not alter physiological or perceptual responses during everyday tasks with NIV use by healthy adults. Future investigations examining the independent and combined impacts of task intensity, extreme environments and NIV use will clarify the benefits of NIV for healthy and clinical populations.

Keywords: non-invasive ventilation, hot-humid, tropical, physiological responses, everyday activities, healthy participants

1. Introduction

Non-invasive ventilation systems (NIV), including continuous positive airway pressure (CPAP) and proportional assist ventilation (PAV) techniques improve gas exchange within the respiratory system while reducing stress on the respiratory muscles (Corner and Garrod, 2010; De Sant'anna Jr et al., 2013). These characteristics highlight NIV as an effective treatment for a range of breathing disorders with the benefits of its use for clinical patients widely accepted within the literature (Hess, 2004; Masip, 2007).

The effectiveness of NIV devices has also been extensively studied with healthy participants and was reported to significantly reduce respiratory muscle work in such populations (Babcock et al., 2002; De Sant'anna Jr et al., 2013; Harms et al., 2000). Further, NIV and CPAP devices have been reported to increase time to fatigue and decrease perceived exertion (De Sant'anna Jr et al., 2013), while PAV devices have been shown to prevent diaphragmatic fatigue (Babcock et al., 2002), increase time to exhaustion, reduce maximal oxygen consumption and reduce the rate of change in perceived limb discomfort during exercise (Harms et al., 2000). However, the influence of NIV use on cardiovascular function in healthy participants appears to vary depending on the ambient environmental conditions. For example, De Sant'anna et al. examined 11 healthy males in a temperate environment while they performed high-intensity exercise and reported that heart rate levels were similar for the CPAP and free breathing

conditions. Similarly, Valipour et al. investigated the effects of a non-invasive, nasal positive-airway pressure device on cardiovascular functioning in 10 healthy participants with this device reducing cardiac output and stroke volume, and increasing peripheral resistance. In contrast, Vroman et al. studied the effects of CPAP on five healthy male participants in a hot environment and found heart rate to increase with CPAP use in both sitting and supine positions. This increased cardiovascular stress highlighted an important physiological response and a potential limitation of NIV use within hot environments.

To date, Vroman et al. has been one of the few studies to examine the effects of NIV use in hot environments. However, Vroman et al. did not examine the effect of NIV while participants were performing tasks of everyday living and only included male participants. Furthermore, Vroman et al. did not compare responses between hot and temperate conditions. Consequently their findings were limited with further research needed to examine the effects of hot environments with NIV use. The potential limitations or benefits of NIV in hot environments is important to understand as tropical hot-humid conditions increase stress on the respiratory system (Basu and Samet, 2002). Given the widespread use of NIV for the treatment of respiratory distress and that approximately 50% of the world's population is projected to be living within the tropics by 2050 (Edelman et al., 2014), a greater understanding of NIV use and its outcomes in tropical conditions is warranted. Examination of NIV use within tropical conditions, initially with healthy participants, may provide important considerations for the use of NIV in clinical populations in tropical environments.

The current study aimed to examine the effect of a portable NIV device, within different environmental conditions, on physiological and perceptual responses in healthy participants while they performed a range of everyday tasks of varying difficulty. Based upon the increased strain placed upon the respiratory system in tropical conditions (Basu and Samet, 2002), it was hypothesized that hot-humid conditions would negatively affect physiological responses. Furthermore, as NIV use reduces stress on the respiratory system muscles (Corner and Garrod, 2010), it was predicted that NIV would enhance everyday task completion via improved physiological and perceptual responses within hot-humid conditions.

2. Material and Methods

2.1 Participants

Sixteen (9 males; 7 females) recreationally, physically active, adults volunteered for this study. Their mean age, height, mass and body fat percentage were 23.8 ± 8.1 years, 174.3 ± 10.9 cm, 70.9 ± 14.5 kg, and 19.9 ± 6.0 %, respectively. All were classified as healthy from responses to a general pre-screening questionnaire and exhibited normal lung function (Forced Vital Capacity = 4.7 ± 1.0 L; Forced Expiratory Volume in 1 second = 83.7 ± 5.5 %; peak expiratory flow = 539.5 ± 139.6 L \cdot min⁻¹). All procedures were conducted in a climate controlled chamber under standardised experimental conditions (i.e. temperature of 20-32°C and relative humidity of 30-80%) that were monitored regularly (Kestral 4000, Boothwyn, Pennsylvania). Informed written consent was

provided by all participants in accordance with approval by the local, university, research ethics committee (H4286).

2.2 Experimental design and variables

This study utilised a prototype portable NIV device that delivers adjustable high flow air via nasal cannula during everyday tasks. The difference between our prototype device and traditional CPAP devices (apart from its lightness and portability) was that the device utilized nasal cannula that did not seal off the nose. Subsequently, air pressure was a non-factor for airway support during use of our portable NIV device. It was expected that in all other aspects, our prototype device was comparable to other NIV devices, including CPAP.

The current study used a within participants (2) x (2) design with two independent variables including device use (with or without) and environment (thermo-neutral and hot-humid) influencing the performance of six everyday tasks of increasing intensity (putting on shirt/shoes/trousers, vacuuming, hanging towels, and walking on a treadmill). Participants completed the everyday tasks under four different experimental conditions: use and non-use of the portable NIV device in a thermo-neutral (TN) environment ($22.2 \pm 0.9^{\circ}\text{C}$, $43.4 \pm 2.5\%$ relative humidity); use and non-use of the portable NIV device in a hot-humid (HH) environment ($31.0 \pm 0.5^{\circ}\text{C}$, $71.0 \pm 1.6\%$ relative humidity).

The four conditions were conducted over two sessions with the use/non-use of the portable NIV device in the same environment conducted within the same session. The two sessions were separated by one week with the order of environment, use/non-use of the portable NIV device and task activities randomly allocated. The dependent variables measured during the experimental conditions included heart rate (HR; POLAR, Kuopio, Finland), fingertip oxygen saturation level (O_{2sat} ; Onyx Vantage Digital Pulse Oximeter, Nonin, Plymouth, Minnesota, USA), thermal comfort and sensation, rating of perceived exertion (RPE), and body (aural) temperature (Welch-Allyn 6021, Braun, Germany). Thermal comfort (ranging from 1 = comfortable to 5 = extremely uncomfortable), sensation (ranging from 1 = unbearably cold to 13 = unbearably hot) and rating of perceived exertion (RPE, 6 = no exertion at all to 20 = maximal exertion) were obtained using previously validated scales (Borg, 1982; Gagge et al., 1967).

2.3 Procedures

Participants entered the climate-controlled chamber and remained seated for a 15-minute stabilization period either with or without the portable NIV device, pending randomization. During that time, all dependent variables were recorded at 1-minute intervals. Following the stabilization period, participants completed the tasks with the dependent variables assessed prior to task, upon task completion and at 1-minute intervals thereafter until pre-task levels (i.e. return of at least four of six variables to baseline values) were achieved. Following a further stabilization period, participants completed the remaining condition within that session (i.e. with or without the portable NIV device).

Following each task, participants rated the use of the portable NIV device for noticeability (1 = Extremely noticeable to 5 = Not noticeable), comfort (1 = Very uncomfortable to 4 = Very comfortable) and usefulness (1 = Helped to 3 = Hindered). The portable NIV device (Figure 1) was connected to a lanyard worn around the neck and continuously circulated room air to the participant via a nasal cannula (OPT884 Optiflow, Fisher & Paykel Healthcare Pty Ltd, Melbourne, Australia). A comfortable flow rate (device range of 2-20 L·min⁻¹) was initially established by each participant and maintained throughout each condition.

****Place Figure 1 here****

2.4 Task Descriptions

In a randomized order, participants undertook the following everyday tasks within each condition:

- 1) Shoes – While seated, participants removed their socks and laced shoes and then put them back on including tying shoelaces;
- 2) Shirt – While seated, participants put on an oversize, long-sleeved dress shirt over their current attire, buttoned it up and then removed it.
- 3) Trousers – Participants stood up and don an oversize pair of trousers over their current attire, zipped the pants up and then removed them.
- 4) Hanging towels – While standing, participants removed five wet towels, one by one, from a basket located on the ground and placed those over a 2 metre long rail located 1.8 metres above ground. Once all towels were suspended, participants removed the towels, one by one, folded them and placed them back into the basket at ground level.

- 5) Vacuuming – Participants undertook a self-paced, 5-minute bout of vacuuming a 2m x 2.5m carpeted area.
- 6) Walking – Participants undertook a 5-minute walking bout at a comfortable speed ($5 \text{ km}\cdot\text{hr}^{-1}$) and incline (2%) on a motorized treadmill (TRACKMASTER TMX55, JAS Manufacturing, Carrollton, Texas, USA).

2.5 Statistical Analysis

Data are expressed as mean \pm standard deviation with all data analysed using the Statistical Package for the Social Sciences (SPSS v22, SPSS Inc., Chicago, ILL). To determine the effects of the portable NIV device and the environment, independent of resting values, difference scores were calculated from the baseline and post values for all dependent variables except recovery time (difference score = post value – baseline value). A difference score was not calculated for recovery time as there was no baseline measurement. A series of two-way repeated measures ANOVAs were conducted on the differences between the portable NIV device use (with/without) and environment (TN, HH) for each activity. A repeated measures t-test was conducted on participant ratings of portable NIV device use between the TN and HH conditions. Due to the number of comparisons undertaken, the significance level for all analyses was set at $p < 0.01$.

3. Results

Tables 1 and 2 depict the physiological and perceptual differences between baseline and post-task responses across the four conditions, respectively.

Place Tables 1 and 2 here

Several main effects for environment were detected with significantly greater changes for TN compared to HH for the following physiological responses: HR during the trousers activity (17.1 ± 7.8 vs. 11.3 ± 9.8 bpm, $p=0.005$); and body temperature during the vacuuming (-0.14 ± 0.41 vs. 0.10 ± 0.20 °C, $p=0.006$) and treadmill (-0.22 ± 0.39 vs. 0.10 ± 0.15 °C, $p<0.001$) activities.

Significantly greater changes for HH compared to TN were detected for the following physiological responses: O_{2sat} levels during the shirt activity (1.0 ± 1.9 vs. $-.1 \pm 1.3$ %, $p=0.007$); RPE during the treadmill activity (2.1 ± 1.7 vs. $0.9 \pm .7$, $p=0.003$); body temperature during the trousers activity (0.12 ± 0.25 vs. -0.11 ± 0.35 °C, $p=0.001$); and recovery time during the vacuuming (2.5 ± 1.5 vs. 1.8 ± 0.7 mins, $p=0.009$) and treadmill (4.0 ± 2.5 vs. 2.1 ± 1.0 mins, $p=0.010$) activities.

Heart rate significantly increased during the treadmill activity while using the portable NIV device compared to non-device breathing (29.5 ± 12.7 bpm vs. 22.8 ± 12.0 bpm, respectively, $p=0.008$) regardless of the type of environment. No other main effects for the device were identified.

No interaction effects between the device (with/without) and environment (TN, HH) were identified.

Participants reported that the portable NIV device was ‘noticeable’ and ‘uncomfortable’ in both the TN and HH conditions (Table 3). The average usefulness scores for the portable NIV device use were comparable for both the TN and HH conditions and indicated that participants found the device to neither help nor hinder performance (Table 3). Nose dryness was significantly more comfortable during HH compared to TN conditions (Table 3).

****Place Table 3 here****

4. Discussion

The current study has demonstrated that physiological responses with the use of the portable NIV device use were not influenced by environmental conditions during the performance of everyday tasks in healthy participants. These findings were contrary to Vroman et al. who concluded that the use of a CPAP device increased HR and cardiovascular strain during hot conditions. The effects of temperature for this CPAP-induced HR increase was not discussed as these authors did not compare responses between a temperate and hot environment. Further, only a small number of healthy participants were examined while they were performing strenuous exercise. In contrast, the current study examined a larger sample of participants who performed low-intensity everyday tasks without device-induced changes. Therefore, whether NIV-induced effects may be task and/or intensity dependent remains to be clarified.

Changes in exercise responses due to NIV use have been observed in previous studies. More specifically, De Sant’anna Jr et al. found CPAP use with healthy adults increased

time to fatigue and reduced the rate of perceived exertion recorded during exercise. Similarly, PAV use has been shown to prevent diaphragmatic fatigue, increase time to exhaustion, reduce maximal oxygen consumption and reduce the rate of change in perceived limb discomfort during exercise (Babcock et al., 2002; Harms et al., 2000). These authors noted the beneficial effects of CPAP and PAV use during high intensity exercise (De Sant'anna Jr et al., 2013; Harms et al., 2000). In the current study, no such benefits were noted with NIV use during any low intensity activity. However, a main effect for the portable NIV use, independent of environmental conditions, was identified with greater exercise HR exhibited during the treadmill activity. This result was similar to that reported in hot conditions (Vroman et al., 1985) and again most likely reflected the task intensity rather than environment. Therefore, task intensity may be the primary factor for altering physiological responses with NIV use that should be considered in the future. This is of particular concern for clinical populations for whom the performance of everyday tasks may be more strenuous compared to healthy persons. Future studies should examine the effect of task intensity and NIV use in various environments using a range of populations.

One factor that should be considered when using NIV within tropical conditions is the acclimatisation state of the individuals. Participants in the current study had lived in a tropical, hot-humid environment for >1 year and were regularly exposed to the experimental hot-humid conditions. Thus, participants were acclimatised to the tropical conditions, which results in minimal physiological changes when exposed to hot-humid conditions (de Freitas and Grigorieva, 2014; Taylor, 2006). It remains to be seen whether non-acclimatised persons would respond similarly. Furthermore, the interplay between

acclimatisation, environment, task intensity and population may provide a greater understanding of the factors influencing NIV usage during everyday living.

A key consideration for NIV use is client adherence rates (Aloia, 2011) with nose dryness a common patient complaint that contributes to low adherence (Gay et al., 2006; Lindberg et al., 2006; Sawyer et al., 2011). In the current study, participants reported a significantly greater nasal comfort for the NIV device use in HH conditions compared to the TN conditions. This effect was likely a result of the increased air humidity for the HH compared to TN conditions (71.0 vs 43.4 % relative humidity) that reduced nasal drying. Thus, adherence to NIV use may be greater in tropical environments due to more comfortable nasal airways. Similarly, humidification within NIV devices may play an important contributing factor to NIV adherence. For interest, the current portable NIV device was not able to humidify circulating air, a factor that may need further development for NIV devices.

The sample size and participants used in this study may limit the generalisability of the findings to different populations including clinical populations. However, this study was an initial step in ensuring that NIV use was not harmful for healthy persons affected by an extreme environment. Further, the current study examined the effects of NIV use during everyday task performances only. The deliberate selection of everyday tasks meant that the study design did not address greater task intensities that have been reported to impact NIV use in temperate and hot conditions (Harms et al., 2000; Vroman et al., 1985).

5. Conclusions

Tropical (HH) conditions did not alter physiological and perceptual responses during everyday tasks with NIV use by healthy adults. Furthermore, the current findings suggest that NIV use has minimal impact on healthy participants when performing low intensity activities. Greater increases in task intensity may enhance the physiological effects of NIV with healthy participants. Future research is needed to examine the independent and combined impacts of task intensity, extreme environments and NIV use on daily task performance in healthy and clinical populations. The effects of HH conditions on functioning in clinical patients is particularly important with over half of the world's population expected to live within tropical locations within the next thirty-five years (Edelman et al., 2014).

Author contributions: Literature search (AB, AL), data collection (AL), study design (AL, MG), data analysis (AB, AS, AL), manuscript preparation (AB, AS, MG, AL), manuscript review (AB, AS, MG, AL).

Institution where the study was performed: James Cook University, Townsville, Australia

Meeting where research data was previously presented: Abstract presented at the Townsville Health Symposium, Townsville, Australia, October 7-9, 2015.

Financial support: This study was supported by funding from the Health Research Council of New Zealand (10/473) for the development of the prototype device.

Conflict of Interest: All authors declare that they have no conflicts of interest. Fisher & Paykel Healthcare Pty Ltd (Melbourne, Victoria, Australia) supplied the nasal cannula

for this study and had no involvement with data collection/analysis or manuscript preparation/review.

Acknowledgments

The authors would like to thank all participants, and Leesa Pearce, Radostina Chalakova and Peta Germanotta for their technical assistance with data collection. Fisher & Paykel Healthcare Pty Ltd (Melbourne, Victoria, Australia) are thanked for supplying the nasal cannula for this study and had no involvement with data collection/analysis or manuscript preparation/review.

Funding

This study was supported by funding from the Health Research Council of New Zealand (10/473) for the development of the prototype device.

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Figure 1. The non-invasive ventilation device used during everyday tasks in thermo-neutral and hot-humid conditions.



Table 1. Post- to pre-activity difference scores for physiological responses during thermo-neutral and hot-humid conditions

		Shirt	Shoes	Trousers	Vacuumping	Towels	Treadmill
Heart Rate (bpm)	TND	9.2 ± 5.0	19.9 ± 9.5	17.4 ± 7.2	16.2 ± 8.6	17.4 ± 8.3	27.8 ± 11.8
	TNnoD	10.4 ± 9.2	16.9 ± 9.8	16.9 ± 8.4	14.1 ± 8.9	17.8 ± 9.6	24.1 ± 9.4
	HHD	12.7 ± 6.7	16.0 ± 8.3	15.3 ± 6.6	13.8 ± 8.1	16.6 ± 8.5	31.3 ± 13.7
	HHnoD	5.8 ± 11.2	7.8 ± 11.8	7.3 ± 13.0	10.0 ± 14.1	9.8 ± 13.5	21.5 ± 14.6
Body Temperature (°C)	TND	-0.2 ± 0.2	-0.1 ± 0.4	-0.2 ± 0.3	-0.3 ± 0.4	-0.1 ± 0.4	-0.4 ± 0.3
	TNnoD	0.0 ± 0.4	0.0 ± 0.4	-0.0 ± 0.4	0.1 ± 0.4	-0.0 ± 0.4	-0.1 ± 0.4
	HHD	-0.0 ± 0.1	-0.0 ± 0.1	0.0 ± 0.2	0.0 ± 0.1	-0.0 ± 0.1	0.0 ± 0.1
	HHnoD	0.2 ± 0.3	0.2 ± 0.3	0.2 ± 0.3	0.2 ± 0.3	0.2 ± 0.3	0.2 ± 0.2
O₂Sat (%)	TND	0.1 ± 1.0	0.1 ± 0.9	-0.2 ± 1.7	-0.2 ± 0.9	-0.7 ± 1.5	-1.2 ± 2.5
	TNnoD	-0.3 ± 1.7	-0.3 ± 2.0	-0.3 ± 2.6	0.0 ± 1.9	-0.2 ± 1.8	-0.9 ± 1.8
	HHD	0.3 ± 0.9	0.4 ± 1.0	-0.2 ± 1.1	-0.3 ± 1.2	-0.3 ± 1.1	-0.1 ± 1.5
	HHnoD	1.6 ± 2.9	1.8 ± 4.0	1.8 ± 4.0	0.9 ± 1.1	1.5 ± 3.9	1.1 ± 3.2
Recovery Time (mins)	TND	1.2 ± 0.5	1.6 ± 0.5	1.4 ± 0.5	1.6 ± 0.6	1.6 ± 0.9	2.0 ± 1.3
	TNnoD	1.3 ± 0.6	1.2 ± 0.4	1.3 ± 0.4	2.1 ± 0.9	1.7 ± 1.1	2.2 ± 0.7
	HHD	1.7 ± 0.9	1.6 ± 0.9	2.3 ± 1.4	2.9 ± 1.5	1.9 ± 1.1	4.3 ± 2.7
	HHnoD	1.9 ± 1.1	1.8 ± 0.9	1.4 ± 0.7	2.1 ± 1.5	1.7 ± 1.0	3.8 ± 2.3

Values are mean ± SD; NIV = non-invasive ventilation; TND = thermo-neutral with NIV; TNnoD = thermo-neutral without NIV; HHD = hot-humid with NIV; HHnoD = hot-humid without NIV; O₂sat = fingertip oxygen saturation level

Table 2. Post- to pre-activity difference scores for perceptual responses during thermo-neutral and hot-humid conditions

		Shirt	Shoes	Trousers	Vacuuming	Towels	Treadmill
Thermal Comfort	TND	0.1 ± 0.4	0.1 ± 0.3	0.1 ± 0.3	0.3 ± 0.6	0.1 ± 0.3	0.1 ± 0.4
	TNnoD	0.1 ± 0.3	0.2 ± 0.3	0.2 ± 0.3	0.2 ± 0.3	0.2 ± 0.3	0.3 ± 0.4
	HHD	0.1 ± 0.4	0.1 ± 0.3	0.1 ± 0.4	0.2 ± 0.6	0.1 ± 0.4	0.6 ± 0.6
	HHnoD	0.1 ± 0.5	0.2 ± 0.4	0.1 ± 0.4	0.3 ± 0.6	0.1 ± 0.4	0.4 ± 0.3
Thermal Sensation	TND	0.3 ± 0.7	0.4 ± 0.8	0.3 ± 0.9	0.0 ± 1.0	0.5 ± 1.0	0.4 ± 0.5
	TNnoD	-0.3 ± 0.8	-0.2 ± 0.8	-0.3 ± 0.9	-0.3 ± 1.1	-0.1 ± 1.0	-0.1 ± 1.0
	HHD	0.3 ± 0.8	-0.1 ± 0.3	0.1 ± 0.5	0.3 ± 0.4	-0.1 ± 0.4	0.9 ± 0.8
	HHnoD	0.2 ± 0.8	0.1 ± 0.1	-0.2 ± 1.0	0.3 ± 0.9	0.0 ± 0.6	0.7 ± 0.9
RPE	TND	0.2 ± 0.4	0.4 ± 0.6	0.3 ± 0.4	1.0 ± 1.4	0.6 ± 0.7	0.8 ± 0.8
	TNnoD	0.0 ± 0.0	0.3 ± 0.6	0.2 ± 0.4	0.5 ± 0.7	0.5 ± 0.6	0.9 ± 0.7
	HHD	0.3 ± 0.5	0.4 ± 0.5	0.6 ± 1.1	1.0 ± 1.5	0.8 ± 0.9	2.1 ± 1.8
	HHnoD	0.4 ± 1.3	0.8 ± 1.3	0.7 ± 1.1	1.3 ± 1.6	0.9 ± 1.3	2.1 ± 1.6

Values are mean ± SD; NIV = non-invasive ventilation; TND = thermo-neutral with NIV; TNnoD = thermo-neutral without NIV; HHD = hot-humid with NIV; HHnoD = hot-humid without NIV; RPE = rating of perceived exertion

Table 3. Participant ratings of the non-invasive ventilation device use during everyday tasks in thermo-neutral and hot-humid conditions

	Thermo-neutral	Hot-humid
Noticeability of device ^a	2.9 ± 0.9	2.8 ± 0.8
Comfort of device ^b	2.3 ± 0.6	2.3 ± 0.6
Usefulness of device ^c	2.3 ± 0.4	2.2 ± 0.4
Nose dryness comfort ^b	2.7 ± 0.6	3.1 ± 0.4*

Values are mean ± SD; ^a1 = Extremely noticeable to 5 = Not noticeable; ^b1 = Very uncomfortable to 4 = Very comfortable; ^c1 = Helped to

3 = Hindered; *p<0.01 vs. Thermo-neutral