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ORIGINAL ARTICLE

Effect of respiration, talking and small body movements on blood pressure measurement

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It is accepted that accuracy of auscultatory blood pressure (BP) measurement is influenced by measurement conditions. However, there is little comparative quantitative clinical data. The aim of this study was to provide these data. Auscultatory systolic and diastolic BPs (SBPs and DBPs) were measured in 111 healthy subjects under five different conditions (resting, deeper breathing, talking, head and arm movement). The measurement sequence was randomized, and repeated three times. BPs and their within-subject variabilities were compared with resting values. SBP and DBP changed significantly in comparison with the resting condition: decreasing by 4.4 and 4.8 mm Hg, respectively, with deeper breathing (both $P<0.001$), increasing by 3.7 and 5.0 mm Hg with opposite arm movement, and increasing by 5.3 and 6.2 mm Hg with talking (all $P<0.001$). The mean differences between deeper breathing and talking were 9.7 and 11.0 mm Hg for SBP and DBP. The within-subject variability for repeat measurement of SBP and DBP under resting condition were 3.7 and 3.2 mm Hg and increased for non-resting conditions (all $P<0.05$, except for DBP while talking). We have shown that measurement conditions significantly influence manual auscultatory BPs and their measurement variabilities, and we provide quantitative data to allow comparison of the effects.
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Introduction

Accurate and reliable blood pressure (BP) measurement is important. However, clinically large and apparently random variation in BP measurement results in millions of people being wrongly diagnosed and wrongly treated. It has been reported that a 5 mm Hg error would result in 21 million Americans being denied treatment or 27 million being exposed to unnecessary treatment, depending on the direction of the error.[1]

The gold standard for clinical BP measurement has always been a sphygmomanometer with readings taken by a trained observer using a stethoscope (auscultatory Korotkoff technique). However, this manual technique is often inaccurately performed, partially because, with the increased availability of automated BP devices, the skills necessary for the auscultatory technique are being lost.[2] Measurement errors occur from incorrect patient posture, incorrect arm position, and incorrect cuff position and size.[3–5] It is also generally accepted that inaccuracies are also associated with the conditions in which BP measurements are taken. In clinical practice, the common measurement disturbances influencing BP measurement variability include patient movement, coughing and talking.[3,6–8]

However, even when the measurement conditions are carefully controlled, consecutive BPs measured from the same individual are still highly variable. This is known as short-term within-subject variability and is mainly caused by physiological or biological factors. Respiration is the main cause of short-term variability, which changes the intrathoracic pressure and alters baroreceptor control.[9,10]

To achieve accurate BP measurement, the correct measurement procedure has been described by the American Heart Association.[11] Patients are instructed to relax and not talk or move during the measurement procedure, but there is no specific recommendation on controlling breathing. Although there have been a few studies addressing the effect of talking and slow breathing on BP changes,[6,7,12–14] there is no comprehensive comparative study

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of the effect of a wide range of different measurement conditions, including arm and head movement. Furthermore, in the majority of published studies, the BPs used for analysis were from automated BP devices, and not from auscultatory measurements, and there was no validation of the devices used for non-resting conditions. Quantitative clinical data on the magnitude of the effect of deeper breathing, talking, arm and head movement on auscultatory BP measurements would be important for accurate measurement, for clinical validation of automated BP devices and for contributing to improvements in BP measurement recommendations.

The aim of this study was therefore to quantify the effect of different measurement conditions (resting, deeper breathing, talking, arm and head movement) on auscultatory BP measurement, as well as on the within-subject auscultatory BP measurement variability.

Subjects and methods

Subjects

Normotensive subjects were studied in each of the following age ranges, 20–29 years, 30–39 years, 40–49 years, 50–59 years and over 60 years. At least 20 subjects were studied in each of the five age ranges, with a total of 111 subjects, of which 55 were male and 56 female, with a mean age of 46 years. Detailed subject information including age, sex, height, weight and arm circumference are summarized in Table 1. The investigation conformed with the principles in the Declaration of Helsinki. The study received ethical permission, and all subjects gave their written informed consent.

BP measurement protocol

All BP measurements were taken by the same trained observer in a quiet clinical measurement room. Subjects were seated on a chair with their feet on the floor and their left arm supported at heart level. Before the measurements were taken, there was a 10–15 min rest period to allow cardiovascular stabilization.

Table 1 General data information for the subjects studied

Subject information		
No. subjects	111	
No. male	55	
No. female	56	
	Mean	*s.d.*
Age (years)	46	16
Height (cm)	170	11
Weight (kg)	74	14
Arm circumference (cm)	29	3

Auscultatory systolic and diastolic pressures (SBP and DBP) were measured from the left arm with a clinically validated electronic non-mercury sphygmomanometer, Accoson Greenlight 300 (AC Cossor & Son (Surgical) Ltd, Harlow, UK)[15] and a stethoscope. The cuff pressure was automatically deflated from ~200 to 10 mm Hg at a rate of 2–3 mm Hg s^{-1}.

For each subject, there were three identical sessions separated by a time interval of 3–4 min. The cuff was released from the left arm after each session. Within each session, a series of BP measurements was taken under different measurement conditions, with a 1-min rest interval between each. An initial BP measurement was used to introduce the subject to the measurement protocol. BP measurements were then repeated under five different measurement conditions. For the first four conditions, subjects were asked to breathe deeply and regularly, to talk by counting numbers, to move their head from side to side and to move the right arm forward and backward, which had the effect of introducing a small body movement. A randomized order was assigned for each subject. A fifth measurement was then taken under controlled resting condition. To simplify the description, the five measurement conditions are referred to below as 'breathing', 'talking', 'head movement', 'arm movement' and 'resting'. The conditions were designed to induce small typical effects in clinical practice, with deeper breathing at a level greater than normal breathing, but which could be easily sustained. Head and arm movements were designed to induce small body movements.

During each BP measurement, the electrocardiogram was also recorded simultaneously and digitally to a computer at a sample rate of 2000 Hz for offline heart rate (HR) calculation.

Data and statistical analysis

The overall mean and standard error of the mean (s.e.m.) for SBP, DBP and HR were calculated from all the subjects separately for each measurement condition. Their mean differences between the four active conditions (deeper breathing, talking, head and arm movement) and the resting condition were calculated. All differences were paired values in each subject.

The SPSS software package (SPSS Inc., Chicago, IL, USA) was used to perform repeated measures analysis of variance to study the measurement repeatability and the effect of measurement condition on SBP, DBP and HR. In this analysis, each subject was his or her own control. The *post hoc* Fisher's least significant difference test was used to make individual comparison between means. A *P*-value below 0.05 was considered statistically significant.

Variance analysis was then performed separately for each condition. This allowed us to separate

variability between subjects and changes with time from the residual variability of repeat measurements in our subjects (within-subject variability). Specifically, the within-subject BP variability was determined from the square root of within-subject component of variance.

Results

BP changes over time
The variance analysis showed that there were significant differences between the three repeat sessions for SBP and DBP (both $P<0.001$), with a fall in SBP and an increase in DBP. Between session 1 and session 3, with a time interval of approximately half an hour, overall mean SBP decreased by 2.0 mm Hg ($P<0.001$), whereas DBP increased by 1.4 mm Hg ($P<0.001$). There was no significant change for HR ($P=0.3$).

Effect of different measurement conditions on BP
As the BP changes over time were very small in comparison with changes because of the measurement conditions, the mean of the three repeats for each subject was used to study the effect of the measurement conditions on BP. Figure 1 shows the overall mean + s.e.m. of SBP, DBP and HR for each measurement condition. Data summarizing the mean paired differences between the four active conditions and the resting condition are given in Table 2.

Mean SBP and DBP measured with deeper breathing decreased significantly by 4.4 and 4.8 mm Hg, respectively, in comparison with those for the resting condition ($P<0.001$). Also, they increased significantly by 5.3 and 6.2 mm Hg with talking, and increased by 3.7 and 5.0 mm Hg with opposite arm movement (all $P<0.001$). The mean SBP and DBP differences between deeper breathing and talking were 9.7 and 11.0 mm Hg. However, there was no significant change in both SBP and DBP during head movement (both $P>0.5$).

HR changed significantly only for conditions with the greatest BP changes, decreasing by 1.1 beats min^{-1} when BP decreased with deeper breathing ($P<0.05$), and increasing by 1.6 beats min^{-1} when BP increased with talking ($P<0.001$).

Effect of different measurement conditions on within-subject BP variability
Table 3 shows the within-subject BP variability for each measurement condition. Under resting condition, the within-subject variability for repeat measurement of SBP and DBP were 3.7 and 3.2 mm Hg, respectively. In comparison with the resting condition, the within-subject BP variability of all four active conditions increased (all $P<0.05$, except for DBP while talking).

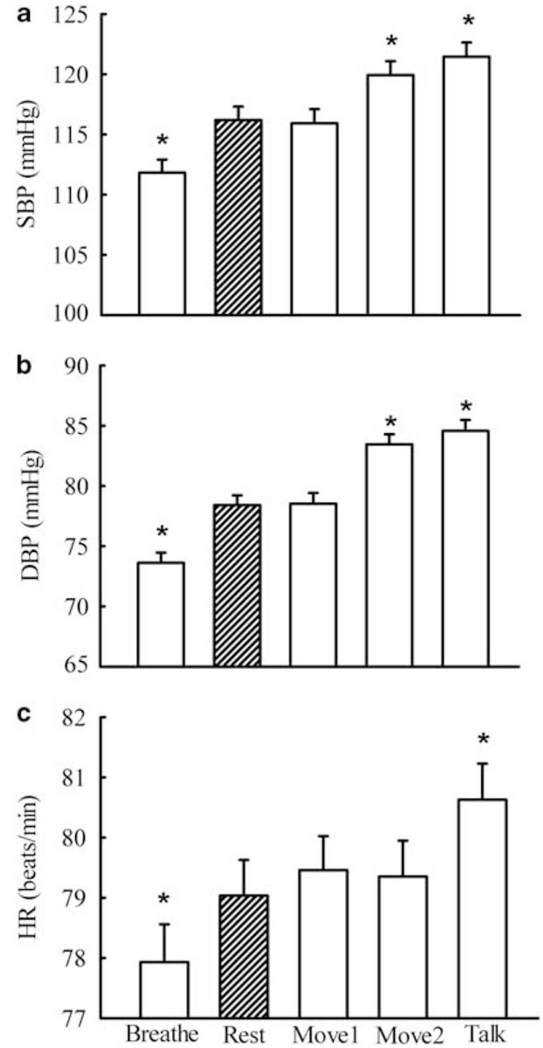

Figure 1 Overall mean + s.e.m. for SBP (**a**), DBP (**b**) and HR (**c**) for each measurement condition (breathe: deeper breathing; rest: resting; move1: head movement; move2: right arm movement; talk: counting numbers). *Significantly different in comparison with the resting condition.

Discussion

In this study, we have shown that measurement conditions had significant influence on the measured manual auscultatory BPs. When compared with the resting condition, a significantly higher BP was obtained with talking and moving the arm without the cuff, and a significantly lower BP was obtained with deeper breathing. These findings further emphasize the importance of carefully controlling the measurement conditions under which BP is taken and standardizing these conditions in population studies, as even a small BP change is important at a population level.

The effect of talking on BP changes will have been caused by physiological effects. Emotional effects have been reported as the cause of talking on increased BP.[6,7] They also reported that different

Table 2 Overall mean differences of BP and HR when compared with the values for the resting condition

Condition	*Mean differences of BP and HR referenced to the resting condition*		
	SBP (mm Hg)	*DBP (mm Hg)*	*HR (beats min*$^{-1}$*)*
Deeper breathing	−4.4[a]	−4.8[a]	−1.1[a]
Head movement	−0.3	0.1	0.4
Arm movement	3.7[a]	5.0[a]	0.3
Talking	5.3[a]	6.2[a]	1.6[a]

Abbreviations: BP, blood pressure; DBP, diastolic blood pressure; HR, heart rate; SBP, systolic blood pressure.
[a]Significantly different in comparison with the resting condition ($P<0.001$, except for HR difference with deeper breathing $P<0.05$).

Table 3 Within-subject variability for repeat measurement of SBP and DBP under different measurement conditions

Condition	*Within-subject variability (mm Hg)*	
	SBP	*DBP*
Resting	3.7	3.2
Deeper breathing	4.7[a]	4.3[a]
Head movement	4.2[a]	3.9[a]
Arm movement	4.5[a]	4.0[a]
Talking	4.6[a]	3.4

Abbreviations: DBP, diastolic blood pressure; SBP, systolic blood pressure.
[a]Significantly different in comparison with the resting condition ($P<0.05$).

types of talking had different effects. In our study, counting numbers was performed and the average increase of BP was over 5 mm Hg. However, in real clinical practice, talking could involve communication of the clinical condition of the patient, which may induce stress and further increase the measured BPs. Le Pailleur *et al.*[7] reported an additional 10 mm Hg increase caused by stressful communication. Such an increase would contribute to the wrong diagnosis of hypertension. Therefore, several international organizations including the American Heart Association and the British and European Hypertension Societies have specifically stressed that talking must be avoided during the measurement procedure to achieve an accurate and reliable BP measurement.[5,11,16]

For the effect of breathing on BP, the reduced manual auscultatory BP in this study agreed with a previous report that deep breathing at 6 breaths min^{-1} reduced BP measured at the finger.[9] In our study, the lower BPs were also accompanied with a small reduction of HR. The underlying mechanism is possibly related to the cardiac reflex with a relative increase in vagal activity and a reduction in sympathetic activity.[17] A few studies have also reported that slow breathing practised routinely is an effective non-pharmacological modality to reduce BP.[12,14,18,19] However, it must be borne in mind that BP changes during expiration and inspiration are different. It has been confirmed that SBP decreases during inspiration and increases during expiration.[10,20] Therefore, the respiration phase at which the BP is being measured manually could be a factor in repeat measurement variability, which was greatest with deeper breathing.

Apart from physiological effects caused by talking and respiration, BP measurement is also affected by external stimuli, such as patient motion. Movement is a major potential source of error for BP measurement. To provide some quantitative evidence for this, in our study, the effects of two typical types of movement in real clinical practice (arm and head movement) were quantified. Although there was no significant change in BPs during head movement, movements from the arm without the cuff increased the manual auscultatory BPs significantly. Our results provide the evidence for the measurement recommendation that small body movements should be avoided during the BP measurement.[11]

As sequential measurements in any individual subject are important, it was interesting to note that, with the measurement condition changing from deeper breathing to talking, a BP difference of 10 mm Hg could be easily introduced. Another common feedback from clinicians and nurses is that even consecutive BP measurements taken under the same measurement condition vary significantly in the same individual.[21] In this study, the within-subject BP variability calculated from three repeat manual BP measurements ranged from 3.2 to 4.7 mm Hg, depending on the measurement conditions. The resting condition produced the smallest variability. However, under the resting condition, there were still about 30% of subjects having consecutive BP differences of more than 4 mm Hg. Therefore, as the recommendation suggests, at least two measurements should be taken carefully at each clinical visit, with a further repeat measurement if there is an uncertain reading. In addition, further studies should be focused more on quantitative studies to investigate the possible factors influencing consecutive BP measurements and to determine which single or combined readings are clinically useful.

It should also be noted that all the factors discussed above that influenced the manual auscultatory BP measurement will also influence automated BP measurements. Therefore, these measurement conditions must also be carefully controlled during automated BP measurements to provide best accuracy for patient benefit.

In summary, this study shows that auscultatory BP is affected by different measurement conditions, providing quantitative evidence that careful control of the conditions before and during measurement is essential for accurate clinical diagnosis.

What is known about this topic

- Accurate and reliable blood pressure (BP) measurement is important. The accuracy of auscultatory BP measurement is influenced by measurement conditions.
- Consecutive BPs measured from the same individual are still highly variable, even when the BP measurement conditions are carefully controlled.
- There is little comparative quantitative clinical data on the effect of a wide range of different measurement conditions on auscultatory BP measurement, including deeper breathing, talking, arm and head movement.

What this study adds

- We have shown that measurement conditions had significant influence on the measured manual auscultatory BPs, providing quantitative data to allow comparison of effects. When compared with the resting condition, a significantly higher BP was obtained while talking and moving the arm without the cuff, and a significantly lower BP was obtained while breathing deeper than normal. The mean differences between deeper breathing and talking were 9.7 and 11.0 mm Hg for systolic BP and diastolic BP, respectively.
- Within-subject BP variability for repeat manual auscultatory BP measurements ranged from 3.2 to 4.7 mm Hg, depending on the measurement conditions. The resting condition produced the smallest variability. Variability increased for non-resting conditions.

Conflict of interest

The authors declare no conflict of interest.

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