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Temporal stability of ambulatory stroke volume and cardiac output measured by impedance cardiography

Annebet D. Goedhart *, Nina Kupper, Gonneke Willemsen, Dorret I. Boomsma, Eco J.C. de Geus

Vrije Universiteit, Department of Biological Psychology, van der Boechorststraat 1, 1081 BT, Amsterdam, The Netherlands

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Abstract

Recently, devices have become available that allow non-invasive measurement of stroke volume and cardiac output through ambulatory thorax impedance recording. If such recordings have adequate temporal stability, they offer great potential to further our understanding of how repeated or chronic cardiovascular activation in response to naturalistic events may contribute to cardiovascular disease. In this study, 24 h ambulatory impedance-derived systolic time intervals, stroke volume and cardiac output were measured in 65 healthy subjects across an average time span of 3 years and 4 months. Stability was computed separately for sleep and daytime recordings. To avoid confounding by differences in posture and physical activity across measurement days, temporal stability was computed using sitting activities only. During the day intraclass correlations were moderate for stroke volume (.29–.46) and cardiac output (.33–.46) and good for systolic time intervals (.55–.81).

When test–retest comparison was limited to two comparable days (two work days or two leisure days), correlations for both SV (.42–.46) and CO (.43–.50) improved. *Conclusion*: Moderate long-term temporal stability is found for individual differences in ambulatory stroke volume and cardiac output measured by impedance cardiography.

Keywords: Sympathetic nervous system; Temporal stability; Hemodynamic regulation; Impedance cardiography

1. Introduction

Frequent and large increases in blood pressure in reaction to psychological stress is hypothesized to be a risk factor for hypertension (Gerin et al., 2000). Blood pressure reactivity is due to a combination of changes in cardiac output (CO) and total peripheral resistance (TPR). The relative contribution of CO and TPR responses to blood pressure reactivity can vary strongly across different types of mental and emotional challenges (Kasprowicz et al., 1990; Lawler et al., 2001; Lovallo et al., 1993). In addition, within a single type of stressor the relative contribution of the TPR response seems to increase with prolonged duration of the stressors (al'Absi et al., 1997; Allen and Crowell, 1989; Carroll and Roy, 1989; Miller and Ditto, 1989, 1991; Ring et al., 2002). Most importantly, large individual differences are seen in the pattern of CO or TPR responses to psychological stress (Brod et al., 1959; Girdler et al., 1990; Kline et al., 2002; Sherwood et al., 1993). Test–retest reliability of CO and TPR reactivity to various laboratory stressors ranges from high across several weeks (Kamarck et al., 1992) to moderately high across 1 week (McGrath and O'Brien, 2001) and across 3 years (Matthews et al., 2002). This is comparable to the short term (Kamarck et al., 1993; Llabre et al., 1993; Swain and Suls, 1996) or longer term (Allen et al., 1987; Matthews et al., 2002; Sherwood et al., 1997) reliability of systolic blood pressure (SBP) and heart rate (HR) responses to laboratory stressors.

CO and TPR can be computed from the conjoint measurement of only three parameters: heart rate (HR), blood pressure (BP) and stroke volume (SV) (Sherwood et al., 1990). It is very easy to obtain HR and BP non-invasively by using ECG recordings and arm-cuff auscultatory methods, respectively. Non-invasive SV has been more elusive, but at least two techniques are now available (Harms et al., 1999; Sherwood et al., 1991) of which impedance cardiography is most often used. In impedance cardiography, two voltage electrodes, typically bands of aluminium-coated Mylar fastened with adhesive strips around the neck and waist, introduce a high-frequency alternating current to the thorax. Two inner and

* Corresponding author. Tel.: +31 20 598 8787; fax: +31 20 598 8832.
E-mail address: ad.goedhart@psy.vu.nl (A.D. Goedhart).

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parallel bands measure the changes in the impedance of the enclosed thorax column (dZ), which is largely a function of aortic blood flow. The impedance cardiogram (ICG) is defined as the first derivative of the pulsatile changes in transthoracic impedance (dZ/dt). From the ICG, two systolic time intervals can be derived, the pre-ejection period (PEP) and left ventricular ejection (LVET). In addition, the blood volume ejection rate of the left ventricle can be estimated by the forward extrapolation of the maximum early slope of dZ or the dZ/d$t_{(min)}$ amplitude. Using the most widely used equation for the estimation of SV, the Kubicek equation (Kubicek et al., 1966), SV is computed as the product of the total duration of systolic ejection and the volume ejection rate, after taking into account the individual's resting thorax impedance and the height of the thorax column enclosed by the measuring electrodes.

Until recently, impedance cardiographic studies have been limited to the laboratory where SV and CO responses are measured in response to short lasting stressors (Light et al., 1998; Matthews et al., 2001; Neumann and Waldstein, 2001; Ring et al., 1999). This leaves uncharted how SV and CO change in response to much longer exposure to stress, such as may occur in the course of a work day. It also remains to be established how SV and CO may change from daytime periods with high sympathetic activation to nighttime periods when sympathetic activation is strongly reduced (Burgess et al., 1997; Lechin et al., 2004; Trinder et al., 2001; van Eekelen et al., 2004). The study of this more prolonged SV dynamics in naturalistic settings requires ambulatory monitoring.

Recently, various systems have become available that allow the ambulatory monitoring of SV through impedance cardiography (Cybulski, 2000; Nakonezny et al., 2001; Sherwood et al., 1998; Willemsen et al., 1996). A number of studies have demonstrated the validity of measuring systolic time intervals, SV and CO with this approach (Riese et al., 2003; Vrijkotte et al., 2004; Willemsen et al., 1996). The temporal stability of individual differences in impedance-derived ambulatory SV and CO remains to be established. In doing so, an important source of confounding will be the potential difference in (physical) activity patterns during the first and the second measurement day. Shifts in posture and physical activity strongly affect cardiac sympathetic drive as well as cardiac afterload and preload which all have an impact on SV (Cacioppo et al., 1994; Sherwood and Turner, 1993). In addition, postural changes are expected to alter the relative position of measuring and current electrodes, the exact shape of the enclosed thorax column and the resulting basal thorax impedance (Z_0) (Laszlo et al., 2001; Mohapatra, 1981; Toska and Walloe, 2002). Both the electrode distance and the basal thorax impedance are important parameters in the Kubicek equation (Kubicek et al., 1966). It is crucial, therefore, to base test–retest comparisons of SV values on carefully selected periods with unchanged posture and physical activity.

A previous study on ambulatory ICG recordings (Riese et al., 2003) showed that, in a small number of subjects, reliable detection of the B-point in the first derivative of thoracic impedance signal (dZ/d$t_{(min)}$) can be difficult. This point corresponds to the opening of the aortic valve and is used to define the PEP but also to compute the dZ/d$t_{(min)}$, a crucial parameter in SV computation. On theoretical grounds, it is more appropriate to measure dZ/d$t_{(min)}$ in relation to this B-point (SV_B) (Debski et al., 1993; Doerr et al., 1981; Mohapatra, 1981), but dZ/d$t_{(min)}$ can alternatively be measured in relation to the dZ/dt = 0 baseline (SV_0) (Sherwood et al., 1991). Since the latter can be more reliably established in all subjects, it is prudent to establish temporal stability for ambulatory SV using dZ/d$t_{(min)}$ both in relation to dZ/dt = 0 (SV_0) and to the dZ/dt B-point (SV_B).

The present study reports on ambulatory SV and CO measured by impedance cardiography in 65 subjects who were tested twice across an average time span of 3 years and 4 months. We established long-term temporal stability of individual differences in 24 h ambulatory SV_0, SV_B, CO_0 and CO_B, while accounting for differences in posture and physical activity on the two measurement occasions.

2. Methods

2.1. Subjects

Participants were all registered with the Netherlands Twin Register (NTR). They came from families that participated in a linkage study searching for genes influencing personality and cardiovascular disease risk, which is described elsewhere (Boomsma et al., 2000). Out of the 1332 twins and siblings who returned a DNA sample (buccal swabs) for the linkage study, 816 were also willing to participate in cardiovascular ambulatory monitoring. Reasons for exclusion were pregnancy, heart transplantation, pacemaker and known ischemic heart disease, congestive heart failure or diabetic neuropathy. Of these subjects a total of 65 (20 male, 45 female) were tested twice separated by a minimum of 2 years and 1 month and a maximum of 4 years and 8 months (mean 3 years and 4 months). At the first test day the age ranged from 18 to 62 years (mean = 30.7, S.D. = 9.7). The Ethics Committee of the Vrije Universiteit approved of the study protocol and all subjects gave written consent before entering the study. No payment was made for participation, but all subjects received an annotated review of their ambulatory heart rate and blood pressure recordings.

2.2. Ambulatory recording

Subjects were invited to participate in the study by letter and subsequently phoned by the researchers to receive additional information on the study, and to make an appointment for 24 h ambulatory monitoring. The first ambulatory measurement took place during a representative work day (or a day with representative housekeeping chores for those who were not employed). The second ambulatory measurement day took place during a comparable (work) day for most of the subjects, but 17 subjects would only participate if the repeated measurement was scheduled on a leisure day. On the day preceding monitoring and on the monitoring day itself subjects were asked to refrain from leisure time exercise or heavy physical work. Subjects were visited at home between 7:00 and 10:00 a.m., and fitted with the Vrije Universiteit Ambulatory Monitoring System (VU-AMS46; de Geus et al., 1995; Riese et al., 2003; Willemsen et al., 1996). They received detailed instructions to regularly check the 'all clear' signal of the device (a small blinking light on the side of the device), and how to proceed in case of suspected device malfunction. The VU-AMS produced an audible alarm approximately every 30 min (±10 min randomized) to prompt the subject to fill out an activity diary. They were instructed to write down their physical activity and bodily postures during the last 30 min period in chronological order. Diary prompting was disabled during sleep, but regular beat-to-beat recording of the ICG was maintained throughout the night. The following day the participants were visited again to collect the equipment.