Circulatory response to postural change in healthy male subjects in relation to age

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Summary
1. The initial heart rate (HR) response evoked by standing up and 70° head-up tilt from the supine resting position, as well as the changes in HR and blood pressure after 1–2 min in the upright position, was analysed in teenage boys (aged 10–15 years) and healthy old men (aged 60–90 years).
2. Standing up induced a characteristic temporary HR increase that lasted 20 s and far exceeded the gradual initial HR rise induced by head-up tilt. The main effect of age on the initial HR transients was a definite diminution of the response.
3. After 1–2 min standing and tilting, young subjects showed a pronounced increase in HR and diastolic pressure with little change in systolic pressure. In contrast, old subjects showed a lesser increase in HR and diastolic pressure and a decrease in systolic pressure. A fall in systolic pressure of greater than 20 mmHg after 1 min of active standing was, however, not observed.
4. It is concluded that the circulatory adjustment to the stress of postural change differs markedly between young and elderly subjects. In healthy old subjects marked postural hypotension appears to be rare.

Key words: age, orthostatic reflexes, vagal heart rate control.

Abbreviation: HR, heart rate.

Introduction
In previous investigations on the initial circulatory adjustment to postural change, we reported that standing evokes a characteristic transient circulatory response, which appears to be related to the active use of muscles during standing up [1–3].

Ageing affects the magnitude of the steady state differences in the circulation between supine and upright postures [4–7]. In the elderly a large fall in blood pressure after arising is often described [5, 6, 8–15]. Few data, however, are available on the effect of age on the initial transient circulatory responses induced by postural change [16–20].

Most of the studies on orthostatic adaptation at old age have been performed in institutionalized and more or less disabled people [8–11, 13, 15, 18]. Data on healthy elderly subjects living at home, however, are scarce. Therefore, we compared both the initial heart rate (HR) response evoked by standing up and 70° head-up tilt and the changes in HR and blood pressure after 1–2 min in upright position in young (10–15 years) and old (60–89 years) healthy male subjects in a general practice.

Methods
Teenage schoolboys were asked to participate when they sought medical advice for trivial ailments (group I). Healthy male subjects (aged 60–69 years) were selected when they applied for a medical certificate for a driver's licence (group II). Physically active older men living at home were selected from volunteers who attended an old people's community centre daily to participate in social events like folk dancing [groups III (70–79 years) and group IV (80–89 years)].

Subjects were recruited until there were 10 apparently healthy subjects in each group. The following entry criteria were used for all groups: subjects with a history of diabetes mellitus, cardiopulmonary, neurological or other major systemic disease or subjects using medications were...
excluded. In the remaining subjects a physical examination was performed, an electrocardiogram was obtained and a urine sample was checked for glucosuria.

At the start of the study we decided to accept as the upper limit of blood pressure supine values of 140/90 mmHg in group I, 160/90 mmHg in group II, 170/90 mmHg in group III and 180/90 mmHg in group IV. These upper limits were chosen to exclude subjects with high blood pressure, taking age into account [21]. Subjects with marked emphysema, varicosity, glucosuria and other obvious abnormalities, and subjects with electrocardiographic evidence of a previous myocardial infarction, ST segment depression or rhythm disturbances, were also excluded.

Four of group II and 22 of groups III and IV subjects had to be excluded for one or more of the above mentioned criteria. Another five subjects in the older age groups were excluded because of frequent ectopic beats during the experimental procedures. The remaining older subjects in their active years had all been handworkers and were still physically active (e.g. cycling and folk dancing).

The experiments took place in the morning at least 2 h after breakfast; coffee and smoking were not allowed from the previous evening on. The examination room temperature was kept at 22°C. The instantaneous HR responses induced by active standing up and by a 70° passive head-up tilt were determined by a cardiotachometer [1].

Standing up was accomplished in 2–3 s by the teenage boys and in 3–4 s by the men in the age range of 60–69 years. It took the older subjects 3–9 s to assume the upright position. Head-up tilt was accomplished by the experimenter in 3 s in all subjects. Subjects remained in the upright position for 2 min. The standing-up and tilting manoeuvres were repeated three times; each manoeuvre was preceded by a period of supine rest of 5 min. The median response of the three measurements was determined [1, 3].

The initial HR response on standing in young subjects is usually bimodal (see Fig. 1a) [1]. Heart rate was determined at instants $t = -10, -5, -1, 0, 1, 2, t_a$ (time at peak a), $t_b$ (time at valley b), $t_c$ (time at peak c), $t_d$ (time at valley d), 30, 60 and 120 s. The HR response to tilt was measured at the same instants [1]. Supine control values for HR were averaged over a 30 s period before the changes of posture and the responses were expressed as changes from control. Blood pressure was measured by the cuff method at rest and after 1 min of standing and tilt (diastolic pressure phase V). Vagal HR control was assessed by measuring its variations during forced breathing and was expressed as the inspiration—expiration difference [16].

![Fig. 1. Examples of HR changes evoked by standing (*) in a young subject (a) and an older subject (b). The initial HR response is usually bimodal in young subjects. a and c denote the primary and secondary peaks respectively; b and d denote the primary and secondary valleys respectively. A primary peak is usually not observed in older subjects.](image-url)
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Statistics

Results are given as means ± SEM. Differences between paired observations were tested using the paired two-tailed Student’s t-test. Differences among the four different age groups were analysed with analysis of variance and the two-tailed unpaired Student’s t-test [22]. A P level of <0.05 was considered to indicate a significant difference.

Results

The basic characteristics of the four age groups are given in Table 1.

Initial HR changes on standing up (Fig. 2, Table 2)

Within 1 s after the onset of standing HR started to increase rapidly in all subjects. A true first peak (a, Fig. 1a) was present in all subjects in group I, in seven out of 10 in group II, in two out of 10 in group III and two out of 10 in group IV subjects. In case the peak a and the valley b were absent (Fig. 1b) the HR at 4 and 7 s was determined instead (mean delay at peak a and valley b, respectively, in the seven group II subjects with a true first peak). In group I the primary HR increase reached a peak of 32 beats/min after 3 s, diminished briefly to 29 beats/min at 5 s and increased again to a maximum of 38 beats/min at 12 s. Between 12 and 19 s HR decreased rapidly to control values and increased again gradually afterwards. The primary HR rise (peak a) was less in the older age groups. In group III and IV subjects peak c was also reached after about 12 s, but the HR increment was less than in group I subjects. The HR responses at valley d did not differ significantly in the four age groups.

Initial HR changes on head-up tilt (Fig. 2, Table 2)

Tilt induced a more gradual HR increase in all four age groups. The HR increase was less steep in the older age groups. Standing up and tilting differed significantly in all four age groups with regard to peak a, valley b and peak c (P < 0.001). At valley d no significant differences were found.

HR and blood pressure changes after 1–2 min in the upright position (Table 3)

The HR increments after 2 min standing and tilt were less in the older age groups. Group I subjects showed little change in systolic pressure 1 min after the change to the upright posture. A significant fall in systolic pressure was found in group III subjects after 1 min of standing (P < 0.05) and in groups III and IV subjects after 1 min of head-up tilt.
Fig. 2. HR changes induced by standing (——) and head-up tilt (-----) in different age groups. HR responses to active and passive changes of posture (*) differed distinctly for about 20 s and decreased with age. The curves represent mean values for the four age groups.

(P < 0.001). A fall in systolic blood pressure of more than 20 mmHg was not observed after 1 min of active standing, whereas it was present in four subjects of groups III and IV after 1 min of passive head-up tilt.

In group I diastolic pressure increased by more than 10 mmHg on average after 1 min standing and tilt. There was a significantly smaller rise of diastolic pressure in the older age groups, especially after head-up tilt. In groups III and IV no significant rise in diastolic pressure was found after 1 min standing and head-up tilt.

Discussion

In previous studies [1–3] on the initial circulatory responses to change of posture in healthy adult subjects, we reported that active and passive changes of posture induce distinctly different initial circulatory responses, which appear to be related to the active use of muscles during standing up [1, 2]. The present study complements this earlier work. It extends the age span of our observations from young and older adult subjects [1–3, 16] to both teenage schoolboys and old men.

Our findings show both in old age and young distinctly different initial HR transients induced by standing up and head-up tilt (Figs. 1 and 2, Table 2). The main effect of age on the initial HR transient on standing is a pronounced flattening of the response. The magnitude of the initial HR response induced by standing in relation to age (Fig. 2) is in excellent agreement with previous reports [16, 17, 20]. The blunted initial HR rise in the elderly cannot be fully interpreted without accounting for a possible difference in the initial transient fall in blood pressure [1, 2] between age groups. Beat to beat changes in blood pressure were not monitored in the present study. A recent study [20] reported, however, that the initial blood pressure dip was in fact significantly less in older than in young adult subjects. This issue needs further evaluation. Diminished cardiac vagal responsiveness at old age has been attributed to depressed baroreflex sensitivity [23, 24]. It has been suggested that impairment of afferent and/or central baroreflex mechanisms could result in a reduction of cardiac vagal tone [24]. This view presupposes intact efferent cardiac vagal pathways in old age. Non-baroreceptor mediated cardiac vagal control can be assessed by investigating the instantaneous HR changes after forced breathing [16], at the onset of exercise (muscle–heart reflex) [1–3, 25, 26] and the HR response after atropine [27, 28]. The fact that vagally mediated HR responses evoked by different afferent stimuli uniformly decrease with age (Figs. 1 and 2, Tables 1 and 2) [16, 20, 23, 24, 27] can in our view most simply be accounted for by functional changes in their common final pathway, i.e. the efferent vagal fibres and the sinus node. Consequently, the HR response induced by changes in blood pressure is not an adequate parameter to use in the assessment of afferent and central baroreceptor pathways in the elderly, but only of the overall baroreflex loop response.

After 1 min standing, systolic pressure showed little change in the youngest age group, but had decreased in the oldest age groups (Table 3). A decrease of more than 20 mmHg in systolic pressure after 1 min of active standing was, however,
| Table 2. Initial heart rate response to standing and head-up tilt from control for different age groups
| Values are means ± SEM. |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                                | HR response (beats/min) |                                |                                |                                |                                |                                |
|                                | Group I (10–15 years) | Group II (60–69 years) | Group III (70–79 years) | Group IV (80–89 years) |                                |                                |
| Peak a                          | Standing          | 32 ± 3            | 23 ± 2            | 15 ± 2            | 14 ± 2            | I vs II P < 0.05 I vs III, IV P < 0.001 |
|                                | Tilt              | 9 ± 2             | 6 ± 1             | 4 ± 1             | 4 ± 1             | I vs III, IV P < 0.05 |
| Valley b                        | Standing          | 29 ± 3            | 18 ± 2            | 16 ± 2            | 16 ± 2            | I vs II P < 0.01 I vs III, IV P < 0.001 |
|                                | Tilt              | 9 ± 1             | 4 ± 2             | 2 ± 1             | 4 ± 1             | I vs II, IV P < 0.05 I vs III P < 0.01 |
| Peak c                          | Standing          | 38 ± 3            | 23 ± 2            | 17 ± 2            | 17 ± 3            | I vs II, III, IV P < 0.001 |
|                                | Tilt              | 10 ± 3            | 2 ± 2             | 3 ± 1             | 7 ± 2             | I vs II, III P < 0.05 |
| Valley d                        | Standing          | 3 ± 2             | 6 ± 4             | 7 ± 1             | 6 ± 2             |                                |
|                                | Tilt              | 6 ± 3             | 2 ± 2             | 4 ± 1             | 6 ± 2             |                                |

| Table 3. Changes in heart rate and blood pressure after 1–2 min in upright position, expressed as change with respect to control level |
| Values are mean ± SEM. |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                                | Group I (10–15 years) | Group II (60–69 years) | Group III (70–79 years) | Group IV (80–89 years) | Statistical significance |
| ΔHR

|Standing          | 14 ± 2            | 10 ± 3            | 11 ± 2            | 8 ± 1            | I vs II, III, IV P < 0.001 |
| Tilt              | 18 ± 1            | 5 ± 2             | 8 ± 1             | 7 ± 2             | I vs II, III, IV P < 0.001 |
| ΔHR

|Standing          | 23 ± 2            | 12 ± 3            | 10 ± 2            | 7 ± 1             | I vs II P < 0.01 I vs III, IV P < 0.001 |
| Tilt              | 20 ± 2            | 10 ± 3            | 11 ± 2            | 7 ± 2             | I vs II, III P < 0.01 I vs IV P < 0.001 |
| Δ Systolic

|Standing          | 3 ± 2             | -2 ± 4            | -9 ± 4            | -5 ± 3            | I vs III P < 0.01 I vs III, IV P < 0.001 |
| Tilt              | -2 ± 3            | -10 ± 4           | -18 ± 3           | -10 ± 2           | I vs II, IV P < 0.05 I vs III P < 0.001 |
| Δ Diastolic

|Standing          | 12 ± 3            | 9 ± 3             | 2 ± 1             | 4 ± 2             | I vs III P < 0.01 I vs IV P < 0.005 |
| Tilt              | 11 ± 1            | 6 ± 2             | -1 ± 1            | 1 ± 2             | I vs III P < 0.05 I vs III, IV P < 0.001 |

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found a decrease in systolic blood pressure of more than 20 mmHg after standing in a large percentage of older subjects [8–15]. A marked decrease in systolic blood pressure after standing was reported in cases of high blood pressure [12, 14, 15], cerebrovascular insufficiency [9, 11, 13, 15], varicosis [8, 10] and various other pathological states [8, 10]. The absence of marked orthostatic hypotension in the present study is probably related to the selection of healthy and physically active subjects, with a normal blood pressure as related to their age [21].

The decrease in systolic blood pressure in the older age groups was more pronounced after passive head-up tilt than after active standing (Table 3). Passive tilting, therefore, seems to impose a greater orthostatic stress in the elderly than active standing. After 1–2 min of standing and head-up tilt young subjects showed a large increase in HR and diastolic pressure (Table 3), implying a marked increase in efferent sympathetic activity [5]. More thoracic blood volume displacement to the lower parts of the body due to greater peripheral venous distensibility in the young is a possible explanation for this observation [7, 29]. Our finding in the oldest age groups of a fall in systolic pressure, but smaller increases in HR and diastolic pressure, after prolonged orthostatic stresses is in line with previous observations [4–7, 14]. The mechanisms underlying these blunted sympathetic cardiovascular reflex responses in the elderly are not clear; decreased responsiveness of the arterial baroreceptor reflex and/or an age related decline in the cardiovascular response to adrenergic stimulation due to decreased receptor function have been postulated [5–7, 30].

Acknowledgments

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References

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