Measuring vibration threshold with a graduated tuning fork in normal aging and in patients with polyneuropathy

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Abstract

Objective—To provide clinically useful vibration threshold normal values.

Methods—The graduated Rydel-Seiffer tuning fork was evaluated in 198 healthy controls and 59 patients with a polyneuropathy. The measures were done in triplicate at four locations: the distal interphalangeal joint of the index finger, ulnar styloid process, interphalangeal joint of the hallux, and internal malleolus. The values obtained with this tuning fork in healthy controls and patients with polyneuropathy were compared with the values of an electronic device, the Vibrameter.

Results—Vibration sense was better perceived in the arms compared with the legs. There was a significant age related decline of vibration sense at all locations. The values from the Rydel-Seiffer tuning fork and the Vibrameter were significantly correlated in both groups. The sensitivity of these two instruments for the four sites examined in the polyneuropathy group ranged from 29–76% and 31–73%, respectively and was the highest at the hallux for both instruments.

Conclusion—This study provides clinically useful normal values of vibration threshold for the Rydel-Seiffer tuning fork. This is a simple and easily applicable instrument that assesses vibration sense semiquantitatively and should therefore have a place in routine neurological examination.

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Keywords: vibration sense; graduated tuning fork; aging

Participants and methods

Healthy controls

Healthy controls were recruited from hospital personnel, companions (relatives, friends) of patients visiting our outpatient clinic, and from homes for elderly people. Two hundred and fourteen potential controls were interviewed and examined. Those with sensory symptoms, sensory signs including absent vibration sense, a history of alcohol misuse, using drugs which may cause a polyneuropathy or influence their cooperation, and those with a disease which might induce a polyneuropathy, were excluded from the study. The selected participants had a lucid consciousness and their history did not show any mental or psychological illness. Standard neurological examination was performed with special interest in the sensory qualities. Six age groups (<40, 40–49, 50–59,
of about 35 participants. Sixteen subjects (nine men; seven women; mean age 81 (SD 8.5) years; range 65–93 years) were excluded from analysis, based on absent vibration perception in at least one region tested. Eight had an absent vibration sense at the hallux and the internal malleolus, seven only at the hallux, and one only at the internal malleolus. Nine subjects had absent and four decreased (−3/−3) ankle jerks. The ankle reflexes were normal in the remaining three patients. These patients were considered to have subclinical disease. The problem of the selection of participants for normal vibration threshold values is discussed later.

PATIENTS WITH POLYNEUROPATHY
Fifty nine ambulatory patients from our outpatient clinic (31 men; 28 women; mean age 56.8 (SD 15.9) years; range 14–87 years) with a clinical and electrophysiologically supported polyneuropathy were enrolled in this study. They were stratified into the same age groups described above, and sex. Each age group consisted of about 10 participants. These patients had a mild polyneuropathy with limited sensory disturbances and walking problems. The aetiologies of the polyneuropathies were diabetes mellitus (11 cases), hereditary motor sensory neuropathy type I (five cases), and type II (two cases), systemic disease (three cases), amyloidosis (three cases), drug induced (two cases), thyroid dysfunction (one case) and vitamin B12 deficiency (one case). Fourteen patients had a chronic idiopathic axonal polyneuropathy. In 17 cases no cause was determined.

ASSESSMENT TOOLS
The Rydel-Seiffer tuning fork is a graduated fork which determines the ability of subjects to discriminate various vibration intensities. The two arms of this tuning fork bear calibrated weights at their extremities (fig 1). A triangle and an arbitrary scale from 0 (minimum score) to 8 (maximum score) imprinted on the weights allow assessment of vibration threshold. Once the arms are swinging, the fork vibrates at 64 Hz and the triangles on the weights appear double. The intersection of these two virtual triangles moves from 0 to 8 in an exponential way with decreasing vibration amplitude. The vibration extinction threshold is considered as the nearest value to the apparent point of intersection of the virtual triangles when the subject indicates that vibration is no longer perceived. The Vibrameter (Somedic, Stockholm, Sweden, Type III) is a device which determines vibration sense electronically. It has been extensively described by Goldberg and Lindblom and consists essentially of a hand held vibrating probe which vibrates at 100 Hz. The vibration amplitude of this probe increases from zero to a maximum of 399.9 μm.

TEST PROCEDURES
All participants gave informed consent before the study. All measurements were performed by one investigator (RvK) and the vast majority
Vibration threshold values obtained by the Rydel-Seiffer tuning fork at the hallux. Residual standard deviation (SDres = residual standard deviation around the mean regression line)=$0.99$; $y$ mean$\pm 0.26 \times age$; $y$ 5%=$5.75 \pm 0.26 \times age$.

Vibration threshold values obtained by the Rydel-Seiffer tuning fork at the internal malleolus. Residual standard deviation (SDres = residual standard deviation around the mean regression line)=$0.89$; $sex = 1$ (male); $sex=0$ (female). $y$ mean$\pm 0.51 \times sex$; $y$ 5%=$4.82 \pm 0.51 \times sex$.

Figure 4

Figure 5

of the assessments took place in the morning. Vibration threshold was assessed at the dorsum of the distal interphalangeal joint of the index finger, ulnar styloid process, dorsum of the interphalangeal joint of the hallux, and internal malleolus. The examination was always performed at the right side of the body with the exception of those with an injury or malformation at that particular side. The measures were obtained in a quiet, comfortably warm, central heating temperature controlled room at our outpatient clinic or in bedrooms of homes for elderly people (20°C-22°C). The tuning fork was applied as perpendicular as possible resting on its own weight with the arms of the fork swinging maximally. The participants were asked to lie at ease in a supine position and indicate the moment when they no longer perceived the decreasing vibration stimulus. The readings of three repeated tests were averaged and considered the vibration threshold for that particular site of examination. In addition, vibration sense was assessed with the Vibrameter in half of the selected healthy controls of each age group, stratified for sex (48 men; 52 women; total n=100), and all patients with polyneuropathy. Vibration threshold was measured according to the method of limits. The subjects were asked to indicate when the vibration stimulus was felt for the first time (perception threshold) and when this stimulus disappeared again (disappearance threshold). The average of these three paired measurements was considered the vibration threshold at the location investigated. The Vibrameter was applied resting on its own weight and its equilibration was electronically controlled. Each cycle of measurement included catch trials with a resting probe.

**STATISTICS**

Vibration threshold reference values for the Rydel-Seiffer tuning fork were calculated for the four sites examined, depending on age and sex, using linear and quadratic regression analysis at a chosen specificity of 95%. The 5% lower limits for the Rydel-Seiffer tuning fork were estimated for each site of examination as the mean−1.65*Sres. The mean was defined as the mean vibration threshold for a certain age (and sex) and Sres was considered the residual standard deviation around the regression line. The 95th percentile vibration threshold values for the Vibrameter were also calculated. The obtained limits were estimated and further used to determine new specificities and sensitivities for both instruments. A vibration sense was considered to be abnormal if the corresponding value was below the 5% lower limit when examined with the tuning fork or above the 95th percentile vibration value when investigated with the Vibrameter at the same site of examination. The correlation between the two instruments was analysed by Spearman’s rank correlation test. All analyses were performed using Stata 5.0 for Windows 95 (Stata Statistical Software: Release 5.0. 702 University Drive East, College station, TX: Stata Corporation 1997). A p value<0.05 was considered to be significant.

**Results**

The whole procedure of assessing vibration sense with the Rydel-Seiffer tuning fork took about 5 minutes, whereas measurements with the Vibrameter needed 10–15 minutes to be completed. In the healthy controls, there was a significant regression between age and the acquired vibration threshold values for the tuning fork at each site of examination (p<0.0001). The corresponding graphics show for each location that the vibration threshold values decreased with aging (figs 2–5). The equations obtained were linear at each site examined, with the exception of the internal malleolus. At this, the vibration thresholds had a quadratic regression on age. Only at this location, a significant regression was also found between the vibration values and sex (p<0.0001). The calculated vibration thresholds at this side were 0.51 higher (scale 0–8) for women than men. The 5% lower limit values were calculated for each age (and sex) at each location and additionally translated for use in clinical practice (table 1). The values for vibra-
Table 1  Normal vibration threshold values (5% lower limit) in healthy controls (with the Rydel-Seiffer tuning fork)

<table>
<thead>
<tr>
<th>Age (y)</th>
<th>Values</th>
<th>Age (y)</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;40</td>
<td>&gt;6.5</td>
<td>&lt;40</td>
<td>&gt;4.5</td>
</tr>
<tr>
<td>41–85</td>
<td>&gt;6.0</td>
<td>41–60</td>
<td>&gt;4.0</td>
</tr>
<tr>
<td>&gt;85</td>
<td>&gt;5.5</td>
<td>&gt;61–85</td>
<td>&gt;3.5</td>
</tr>
</tbody>
</table>

Sites of examination: dorsum of the distal interphalangeal joint of the index finger, the ulnar styloid process, dorsum of the interphalangeal joint of the hallux, and the internal malleolus. Values are 0–8; the vibration threshold values are presented in rounded numbers.

For both upper and lower extremities, some sites examined with abnormal sense of vibration include:
- Hallux: 45% (76%)
- Internal malleolus: 34% (58%)
- Index finger: 19% (32%)
- Ulnar styloid process: 17% (29%)

Testing sites at a chosen definition for having polyneuropathy were combined in each participant to calculate new sensitivities and specificities at a chosen definition for having polyneuropathy. The 5% lower limit values obtained with the tuning fork was rarely seen. The obtained normal vibration values were higher for the arms than for the legs. These findings have also been reported by others.

The present study provides clinical useful normal values for the vibration sense using the graduated Rydel-Seiffer tuning fork at four sites of examination. These normal values are different from those provided by the literature. Claus et al stated that subjects up to 40 years should score at least 6/8 and those older than 40 at least 4/8.7 The difference may be explained by the difference in study design: their population consisted of only 73 healthy controls and no information was given on stratification for age and sex. Moreover, examination was performed only at the internal malleolus and thus no values were provided for the arms or the hallux. Three other studies provided normal values for only one site of examination, but unfortunately these values were presented in a graphical way and not translated for general clinical use.8–10 Thivolet et al, however, examined 88 healthy controls at four different sites, but only the hallux was graphically presented.8

We found an age related decrease in vibration sense for all four sites of examination. Pearson11 was the first to report an age related decrease and subsequently, numerous reports have confirmed this finding.5 6 43 25 27–29 The significance of this decline is not clear and neither is its cause. However, it is known that degenerative transformations of the Pacinian corpuscles, demyelinisation, and fibre loss in peripheral nerves occur with aging.11 12 Degenerative changes also occur in the CNS with advancing age which may also account for the decreasing vibration sense.18 24–26 The decrease of vibration sense with age is, however, gradual and there is no trend towards absent vibration sense in healthy old persons, not even at the hallux (fig 4). We are inclined to conclude that absence of vibration sense even in elderly people should therefore be considered as abnormal. Many experienced investigators and neurologists make explicit references to a “non-specific neuropathy of aging” and suggest that these changes occur uniquely during the aging of peripheral nerves.24 26 Interpretation of an absent distal vibration sense should be carefully taken, and preferably viewed in the context of other symptoms or signs compatible with a polyneuropathy. A thorough evaluation to identify possible causes should always be performed before attributing these abnormalities to aging.

The obtained normal vibration values were higher for the arms than for the legs. These findings have also been reported by others.4

Table 2  Sensitivity of the Rydel-Seiffer (RS) tuning fork compared with the Vibrameter in patients with a mild polyneuropathy (chosen specificity of 95%)

<table>
<thead>
<tr>
<th>Location</th>
<th>RS tuning fork: patients with abnormal vibration (n (%))</th>
<th>Vibrameter: patients with abnormal vibration (n (%))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ulnar styloid process</td>
<td>17 (29)</td>
<td>18 (31)</td>
</tr>
<tr>
<td>Index finger</td>
<td>19 (32)</td>
<td>19 (32)</td>
</tr>
<tr>
<td>Internal malleolus</td>
<td>34 (58)</td>
<td>28 (48)</td>
</tr>
<tr>
<td>Hallux</td>
<td>45 (76)</td>
<td>43 (73)</td>
</tr>
</tbody>
</table>

Sites examined with abnormal sense of vibration:
- 0
- 1
- 2
- 3 or 4

The specificity of 80% and a sensitivity of 83%. The specificity and sensitivity for the Vibrameter were 86% and 78%, respectively. The corresponding specificity and sensitivity when at least two sites investigated showed an abnormal vibration sense was 94% and 63% for the tuning fork, and 98% and 61% for the Vibrameter.

Discussion
The present study provides clinical useful normal values for the vibration sense using the graduated Rydel-Seiffer tuning fork at four sites of examination. These normal values are different from those provided by the literature. Claus et al stated that subjects up to 40 years should score at least 6/8 and those older than 40 at least 4/8.7 The difference may be explained by the difference in study design: their population consisted of only 73 healthy controls and no information was given on stratification for age and sex. Moreover, examination was performed only at the internal malleolus and thus no values were provided for the arms or the hallux. Three other studies provided normal values for only one site of examination, but unfortunately these values were presented in a graphical way and not translated for general clinical use.8–10 Thivolet et al, however, examined 88 healthy controls at four different sites, but only the hallux was graphically presented.8

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The obtained normal vibration values were higher for the arms than for the legs. These findings have also been reported by others.4 A possible explanation for these variances can be found in the differences in length of nerves between the arms and legs. It is known that longer axons are more prone to degeneration of
distal regions, possibly due to a metabolic abnormality leading to failure of axonal transport and subsequent degeneration.27

The sensitivity of the Rydel-Seiffer tuning fork for patients with a polyneuropathy is highly dependent on the selection of patients. In patients with predominantly motor signs and those with only small size myelinated/unmyelinated nerve disturbances it might be expected that the sensitivity for detecting vibration sense abnormalities using this tuning fork will be low. The vast majority of the patients with a polyneuropathy in the present study had limited sensory disturbances and hardly ambulatory problems. These findings might explain the low sensitivity that was found at the sites examined in the arms and the somewhat higher sensitivity for the two locations investigated in the legs.

The vibration threshold values obtained with the Rydel-Seiffer tuning fork showed a significant correlation with those of the Vibrameter. This correlation was, however, moderate and was probably due to an increasing variability between the values obtained with the Vibrameter in participants 50 years and older. A considerable variability when applying the Vibrameter in elderly people has also been reported earlier.23–25 A significant correlation between these two instruments has been shown by others.9–11 Hotta et al found a good correlation between a variant of the graduated Rydel-Seiffer tuning fork and the Vibrameter and stated that the tuning fork provided objective and reliable measurements of vibration sense.14

The pocket sized Rydel-Seiffer tuning fork detected slightly more abnormalities in the selected group of patients with a polyneuropathy than the Vibrameter. The present study also shows that the Rydel-Seiffer tuning fork is easily applicable, does not require long periods of attention, and measures vibration sense quicker than the Vibrameter.

The clinical validity of a screening test depends not only on its simplicity and validity, but also on its reliability and sensitivity to register clinically relevant information. Long term follow up of patients with a polyneuropathy will determine the sensitivity of the Rydel-Seiffer tuning fork to changes in time and will indicate whether clinical improvement correlates with improvement in vibration sense. This is currently being evaluated more extensively in a group of patients with immune mediated polyneuropathy with various degrees of severity. Its interobserver and intraobserver reliability and sensitivity to register changes in time are under investigation.

In conclusion, our findings indicate that the Rydel-Seiffer tuning fork is a simple instrument which rapidly measures vibration sense in a semiquantitative way. Clinically useful vibration threshold normal values are provided for this tuning fork. We propose to incorporate this pocket sized instrument in the routine neurological examination.

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