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Impaired Manual Dexterity and Neuromuscular Dysfunction in Patients with Hand-Arm Vibration Syndrome

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Abstract: Manual dexterity and hand functional difficulties in daily life in hand-arm vibration syndrome (HAVS) were investigated in 29 male patients with HAVS and 30 male controls without occupational exposure to hand-arm vibration. Manual dexterity was assessed by measuring the performance time of picking up and transferring 30 red beans, one by one, from one plate to another. Vibrotactile perception thresholds at 125 Hz and grip strength were also examined. Hand functional difficulties in daily life were surveyed with a questionnaire. The HAVS patients had an increased vibrotactile threshold, decreased grip strength, and low performance in transferring beans. Low performances with transfer times over 53 s (2SD from the mean in the controls) were found in 66% of the HAVS patients and 3% of the controls. Bean transfer times in the patients were correlated with an increasing vibrotactile threshold and decreasing grip strength. The transfer times of the patients were also associated with hand functional difficulties such as picking up coins, turning the pages of a newspaper, buttoning clothes, and pouring from a teapot. The patients with a prolonged transfer time over 60 s (3SD from the mean in the controls) were most likely to have hand functional difficulties. The present findings suggest that measurement of the bean transfer time will serve to assess manual dexterity among HAVS patients, and that impaired manual dexterity in patients may be associated with impaired sensory feedback and muscular dysfunction in the fingers and hands.

Key words: Hand-arm vibration, Manual dexterity, Neuromuscular dysfunction

Introduction

Long-term exposure to hand-transmitted vibration may develop vasospastic and sensorineural symptoms in the hands. Neuromuscular impairments in hand-arm vibration syndrome (HAVS) include numbness and/or tingling, damaged cutaneous perception, impaired manipulative dexterity and reduced grip strength in the hands. In the Stockholm Workshop scale of sensorineural (SN) staging, the 3SN stage is defined as intermittent or persistent numbness, and reduced tactile discrimination and/or manipulative dexterity[1)]. Impaired manipulation can interfere with the social and work-related activities of vibration-exposed workers[2)]. Earlier studies reported hand functional difficulties such as manipulating small objects[3–9)]. It is, therefore, important to clarify hand functional damage in association with daily activity among HAVS patients. However, there are only a few studies which have quantitatively evaluated manual dexterity in vibration-exposed workers or investigated the association between impaired manual manipulation and neuromuscular dysfunction among HAVS patients.

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The authors have previously demonstrated impaired manual dexterity in HAVS patients by measuring the performance time of the buttoning-unbuttoning task and the bean-transferring task[10]. The aim of the present study was to ascertain the usefulness of measuring the bean transfer time for the assessment of manual dexterity and further, to investigate the association between impaired manual dexterity and damaged tactile sensation and muscular weakness among HAVS patients.

Methods

The present subjects were 29 male patients with HAVS under treatment and 30 male controls of similar age (range: 49–66 yr). The mean (standard deviation) age was 59.7 (4.4) yr and 58.5 (4.6) yr, respectively, and did not differ significantly. The patients had mainly used rock drills and pick hammers (n=18) in tunneling, construction and other such works, and chain saws (n=6) in forestry, and other similar types of work (n=5). Their mean treatment years were 4.4 (3.6) yr. Ten of them (34%) had vibration-induced white finger (VWF) and all had finger numbness or tingling. According to the Stockholm Workshop scales, the HAVS patients were classified 19 to 0V, 3 to 1V and 7 to 2V for vascular staging[11], and 3 to 1SN, 9 to 2SN and 17 to 3SN for sensorineural staging[1]. In this study 3SN was defined as severe permanent finger numbness or tingling and vibrotactile thresholds over 17.5 dB at 125 Hz. The controls were composed of office workers, manufacturers, drivers and others who had not been occupationally exposed to hand-transmitted vibration. None of them had white finger, finger numbness or tingling. The present subjects were selected from those without complications relating to finger nerve impairments, such as cerebrovascular diseases, diabetic or alcoholic neuropathies, and severe injuries in the upper extremities. All subjects consented to participate in this study.

Manual dexterity was assessed by measuring the performance time of the bean-transferring task[10]. Subjects were seated on a chair at a desk on which 30 red beans (each about 7×5 mm in size and 0.2 g in weight) were placed on a plate (7.0 cm in diameter). Subjects were asked to pick up 30 beans one by one with the fingers of their dominant hand and to transfer them to another plate about 10 cm away as quickly as possible. The time to complete the task was measured by a stop watch. The trials were performed three times and the performance times were averaged.

Vibrotactile perception thresholds at 125 Hz were measured on the palmar side of the distal phalanx of the index finger with a vibrometer (AU-02B, Rion, Japan), which can generate sine-wave vibrations from –10dB to 40 dB in units of 2.5 dB (0dB = 0.218 m/s^2). Several trials were done, increasing the vibration intensity to set a minimum threshold the subject could perceive. Grip strength was also examined using a grip dynamometer (TK-1201, Takei Co., Japan). In this study the dominant hands were the right hands for all subjects, and hence the examination results were all evaluated on the right hand.

Subjects were also surveyed with a questionnaire about hand functional difficulties in daily life such as buttoning clothes, picking up coins, writing with a pen, dropping objects like a cup, etc. Multiple choice answers for each item were in four categories: without any difficulty, with some difficulty, with much difficulty, and unable to do. For the question of dropping objects, the frequency was questioned: none, several times a year, several times a month, and several times a week.

These examinations were conducted in a room with an ambient temperature of 23–27°C. Index finger skin temperature of all subjects was over 30°C.

Data analyses were made with the Statistical Package for the Social Science (SPSS) version 10.0J for Windows. Comparisons between HAVS patients and controls were made using Student's *t*-test or the Mann-Whitney U-test. Dunnett's *t*-test or Fisher's exact test was also used for comparisons among subgroups of HAVS patients classified by Stockholm Workshop scales for vascular and sensorineural staging, vibrotactile thresholds, and grip strength. Spearman's rank correlations were employed for associations between variables of bean transfer time, vibrotactile thresholds, grip strength, Stockholm Workshop scales for vascular and sensorineural staging, and hand functional difficulties.

Results

As shown in Table 1, bean transfer time was significantly prolonged in the HAVS patients compared with the controls ($p<0.001$). Cut-off values in the bean transfer time were tentatively set at 53 s and 60 s which were calculated as 2SD and 3SD from the mean value in the control subjects, respectively. Exceeding the 2SD cut-off value (over 53 s) was counted as low performance in the bean transferring task in this study, which was encountered in 3% of the controls and 66% of the HAVS patients ($p<0.001$). The HAVS patients also had an increased vibrotactile perception threshold and reduced grip strength ($p<0.001$).

The HAVS patients were divided into three subgroups classified according to the vibrotactile perception thresholds at 125 Hz (under 10 dB, 10 dB+, and 20 dB+) and grip

Table 1. Bean transfer time, vibrotactile perception threshold and grip strength in patients with hand-arm vibration syndrome and controls

	HAVS Patients (n=29)	Controls (n=30)
Age (years)	59.7 ± 4.4	58.5 ± 4.6
Bean transfer time (s)		
< 53	10 (34.5%)***	29 (96.7%)
53 –	7 (24.1%)	1 (3.3%)
60 +	12 (41.4%)	0 (0.0%)
M ± SD	63.7 ± 25.7***	40.4 ± 6.7
Vibrotactile threshold at 125 Hz (dB)		
– 7.5	3 (10.3%)***	28 (93.3%)
10 – 17.5	12 (41.4%)	2 (6.7%)
20 +	14 (48.3%)	0 (0.0%)
M ± SD	19.5 ± 10.1***	1.3 ± 5.5
Grip strength (kg)		
– 19	7 (24.1%)***	0 (0.0%)
20 – 29	15 (51.7%)	1 (3.3%)
30 +	7 (24.1%)	29 (96.7%)
M ± SD	25.2 ± 8.7***	38.8 ± 4.3

***p<0.001, by Mann-Whitney U-test or *t*-test compared with controls. HAVS: hand-arm vibration syndrome. M ± SD: mean ± standard deviation.

strength (under 20 kg, 20 kg+, and 30 kg+), respectively. As shown in Table 2, with increasing vibrotactile threshold and decreasing grip strength in the HAVS patients, the bean transfer time and the low performance tended to increase. A significantly prolonged transfer time was found in the vibrotactile threshold above 10 dB and grip strength below 30 kg in HAVS patients compared with the controls. Spearman's rank correlation coefficients in the HAVS patients were 0.477 ($p<0.01$) between bean transfer time and vibrotactile threshold and –0.524 ($p<0.01$) between bean transfer time and grip strength. Spearman's rank correlation coefficient between vibration threshold and grip strength in HAVS patients was –0.262 ($p>0.05$).

Table 3 shows hand functional difficulties in the HAVS patients surveyed with the questionnaire. Complaints of much difficulty were seen in a relatively small number of the HAVS patients. None indicated "unable to do" hand difficulties. Complaints of hand functional difficulties in the HAVS patients were frequently found in manipulating things such as buttoning clothes, picking up coins, opening

Table 2. Bean transfer time of patients with hand-arm vibration syndrome (n=29) by vibrotactile threshold and grip strength

	Mean (± SD) of age (years)	Mean (± SD) of bean transfer time (s)	Number (%) of low performance over 53 s
Vibrotactile thresholds at 125Hz (dB)			
–7.5 (n=3)	55.7 ± 5.5	52.9 ± 20.4	1 (33.3%)
10 – 17.5 (n=12)	59.5 ± 4.4	61.4 ± 33.0**	6 (50.0%)**
20 + (n=14)	60.6 ± 4.0	68.0 ± 19.5 ***	12 (85.7%) ***
Grip strength (kg)			
–19 (n=7)	60.7 ± 4.5	69.4 ± 20.5**	6 (85.7%)***
20 – 29 (n=15)	60.4 ± 3.9	69.2 ± 30.3 ***	11 (73.3%) ***
30 + (n=7)	57.0 ± 4.8	46.4 ± 6.8	2 (28.6%)

**p<0.01, ***p<0.001, compared with the controls by Dunnett's *t*-test or Fisher's exact test.

Table 3. Hand functional difficulties among patients with hand-arm vibration syndrome

	With some difficulty	With much difficulty	Total
Buttoning clothes	20 (69.0%)	4 (13.8%)	24 (82.8%)
Picking up coins	19 (65.5%)	5 (17.2%)	24 (82.8%)
Opening a jar lid	15 (51.7%)	7 (24.1%)	22 (75.9%)
Writing with a pen	15 (51.7%)	5 (17.2%)	20 (69.0%)
Turning the pages of a newspaper	15 (51.7%)	4 (13.8%)	19 (65.6%)
Pouring from a teapot	17 (58.6%)	0 (0.0%)	17 (58.6%)
Using chopsticks	13 (44.8%)	1 (3.4%)	14 (48.3%)
Dropping objects like a cup	9 (30.0%)	0 (0.0%)	9 (30.0%)
Turning door knobs	6 (20.7%)	1 (3.4%)	7 (24.1%)
Putting on a jacket	6 (20.7%)	0 (0.0%)	6 (20.7%)

Table 4. Hand functional difficulties among patients with hand-arm vibration syndrome by bean transfer time

Bean transfer time (s)	< 53 (n=10)	53–59 (n=7)	60 < (n=12)	Spearman's correlation
Age (years)	58.5 ± 4.6	60 ± 4.1	60.0 ± 4.6	
Picking up coins	6 (60%)	6 (86%)	12 (100%)	0.632**
Turning the page of newspaper	4 (40%)	3 (43%)	12 (100%)	0.563**
Buttoning clothes	6 (60%)	6 (86%)	12 (100%)	0.501**
Pouring from a teapot	4 (40%)	3 (43%)	10 (83%)	0.494**
Using chopsticks	3 (30%)	3 (43%)	8 (67%)	0.322
Turning door knobs	2 (20%)	1 (14%)	4 (33%)	0.303
Opening a jar lid	7 (70%)	5 (71%)	10 (83%)	0.301
Writing with a pen	7 (70%)	3 (43%)	10 (83%)	0.298
Dropping objects like a cup	2 (20%)	1 (14%)	6 (50%)	0.143
Putting on a jacket	2 (20%)	2 (29%)	2 (17%)	0.071

**p<0.01, Spearman's rank correlations between bean transfer time and hand functional difficulties.

Table 5. Bean transfer time of patients with hand-arm vibration syndrome by Stockholm Workshop scales for vascular and sensorineural staging

Symptom	Mean (± SD) of bean transfer time	Number (%) of low performance over 53 s
Vascular staging		
0V (n=19)	62.4 ± 26.9	12 (63.2%)
1V (n=3)	63.3 ± 32.8	2 (66.7%)
2V (n=7)	64.8 ± 22.9	5 (71.4%)
Sensorineural staging		
1SN (n=3)	52.9 ± 20.4	1 (33.3%)
2SN (n=9)	47.6 ± 6.9	3 (33.3%)
3SN (n=17)	74.1 ± 28.2***	15 (88.2%)***

***p<0.001, compared with controls by Dunnett's *t*-test or Fisher's exact test.

a jar lid, writing with a pen, turning the pages of a newspaper, and pouring tea from a teapot. On the other hand, the control subjects rarely complained of hand functional difficulties. Three control subjects individually had some difficulties in picking up coins, opening a jar lid, and turning the page of newspaper, respectively.

Hand functional difficulties among the patients tended to increase, as bean transfer time was prolonged (Table 4). Significant Spearman's rank correlations between bean transfer times and hand functional difficulties were encountered in picking up coins (r=0.632, p<0.01), turning the pages of a newspaper (r=0.563, p<0.01), buttoning clothes (r=0.632, p<0.01) and pouring from a teapot (r=0.494, p<0.01). The HAVS patients with prolonged performance times ≥ 60 s (3SD from the mean in the controls) were most likely to have hand functional difficulties.

As shown in Table 5, the bean transfer time in the HAVS patients was significantly associated with the Stockholm Workshop scales for sensorineural staging (r=0.559, p<0.01), but not with the Stockholm Workshop scales for vascular staging (r=0.066, p>0.05). The bean transfer times were significantly prolonged in the HAVS patients with 3SN compared with the controls (p<0.001), and low performance with prolonged been transfer time ≥ 53 s was also significantly often encountered in those with 3SN (p<0.001). The bean transfer times were not significantly different in the HAVS patients classified by the vascular staging compared with the controls.

Discussion

The present study demonstrated impaired manipulation in HAVS patients by measuring the performance times of the bean transfer task in which subjects are asked to pick up 30 red beans one by one from a plate with their fingers and to transfer them to another plate as fast as possible. HAVS patients had significantly prolonged performance times in the bean-transferring tasks, which were associated with the sensorineural staging of the Stockholm Workshop scales, but not with the vascular staging. These results were in accordance with the findings of our previous study[10]. Additionally, the present study showed that low performance in the bean-transferring task was associated with both increasing vibrotactile threshold and decreasing grip strength, especially with increased vibrotactile threshold over 10 dB (= 0.689 m/s^2) and decreased grip strength below 30 kg, suggesting that impaired manipulative dexterity may be

associated with sensory and muscular dysfunction.

It is known that the ability to manipulate objects relies on the accuracy of the underlying sensorimotor control system for finger movements with an accurate feedback from the mechanoreceptors in the glabrous skin of the digits[12]. Precise control for gripping or picking up objects requires exact sensory information from SAI afferents, and to a lesser extent FAI afferents. HAVS patients often have digital nerve impairments[13, 14] and damaged cutaneous perception in vibration, pain, thermal and tactile perceptions. Impaired vibrotactile perception threshold is reportedly associated with slowed digital sensory nerve conduction[15]. The association between low performance in the bean-transferring tasks and impaired vibration perception in the present study suggests that the impaired manipulation in HAVS patients may be attributed to impaired sensory feedback from the glabrous skin of their fingers and hands.

Impaired manipulation was associated with reduced grip strength as well. It is known that long-term exposure to hand-transmitted vibration causes reduced grip strength and intrinsic muscular dysfunction[16–18]. Biopsies from the abductor pollicis brevis muscle in vibration-exposed workers have shown malalignment of myofibrils[19]. Animal experiments also demonstrated that the directly exposed muscles were more affected than the proximal muscles[20]. Prolonged exposure to hand-arm vibration may damage both the hand muscles and the motor nerves innervating the hand muscles. These muscular dysfunctions might contribute to the reduction of manipulative skills in HAVS patients.

The present study demonstrated hand functional difficulties in HAVS patients. About 60–80% of the HAVS patients had some hand problems in buttoning clothes, picking up coins, opening a jar lid, writing with a pen, turning the pages of a newspaper and pouring tea from a teapot, though patients with great difficulties were not so many. Earlier studies have also reported difficulties manipulating small objects like buttoning clothes in vibration exposed workers[4–7]. Cederlund *et al*. found that 42% of vibration-exposed workers had difficulties in performing daily activities such as writing by hand, picking up needles, opening jar lids, lifting and carrying[8]. Futatsuka and Oka reported that 69% of patients with VWF had hand functional difficulties in buttoning up and 52% in picking up peas[9]. In addition, the present study showed that the performance times of the bean transfer tasks were associated with some hand difficulties in picking up coins, turning the pages of a newspaper, buttoning clothes, and pouring tea from a tea pot. HAVS patients with prolonged bean transfer times over 60 s (3SD cut-off value) were most likely to have such hand difficulties. Thus, bean transfer examinations will serve to evaluate manual dexterity in vibration-exposed subjects, though standardization of the measurements is necessary for generalization. There are as yet only a few studies which have evaluated manipulative dexterity in vibration-exposed workers. Further studies are required to explore neuromuscular dysfunction in HAVS.

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