Behavioural and Societal Sciences
Kampweg 5
3769 DE Soesterberg
P.O. Box 23
3769 ZG Soesterberg
The Netherlands

www.tno.nl

T +31 88 866 15 00
F +31 34 635 39 77
infodesk@tno.nl

TNO report

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Tactile specification of the Elitac tactile display

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Author(s) W.K. Vos

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Contents

1 Introduction

This document lists the specifications regarding the vibration properties of the Elitac modular tactile display. It also describes how these specifications were measured. The tactile display consists of a string of vibration elements (TAC20120801) - also called tactors - that are pressed against the skin with elastic textile (TEX20130201). The tactors consist of K'OTL pancake direct current unbalanced motors (C1226B500F) running on 3.0 Volts and at a maximum rotational speed of 150 cycles/s. The Elitac hardware uses pulse width modulation to control rotational speed of the tactors. The user can select from 4 different rotational speeds, represented as levels numbered from zero to three.

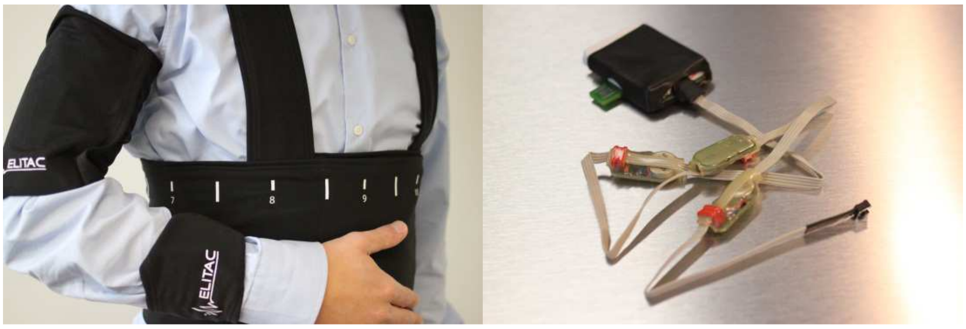

Figure 1 The Elitac modular tactile display. Under the stretchable textile on the left the string of tactors as shown on the right is worn (© Elitac).

2 Method

2.1 Setup

All vibration measurements were done in the anechoic chamber of TNO in Soesterberg, which has a background noise level of less than 20 dBA.
The measurement setup (see Figure 2) consisted of a laptop to control the Elitac display wirelessly through Bluetooth. The display itself was worn around the waist (see Figure 1), with the tactor that was being measured just left of the umbilicus. The long axis of the tactor was in the transverse plane of the body (see Figure 3). The elastic band controlled the amount of pressure on the tactor. Glued to the tactor was a Brüel & Kjær 4393 uniaxial accelerometer to measure the vibration characteristics. Since it is a uniaxial accelerometer, the accelerometer was successively glued in 3 different orthogonal orientations, namely perpendicular, longitudinal and latitudinal (see Figure 3). The acceleration signal was amplified with a Brüel & Kjær 2692 conditioning amplifier. Its band pass filter was set to 1 Hz – 1 kHz and its output was connected to a Tektronix 2012B digital oscilloscope. The waveforms were saved to a USB stick inserted in the oscilloscope. A Brüel & Kjær 2236 integrating sound level meter was used to measure the sound production of the tactors at a distance of 10 cm.

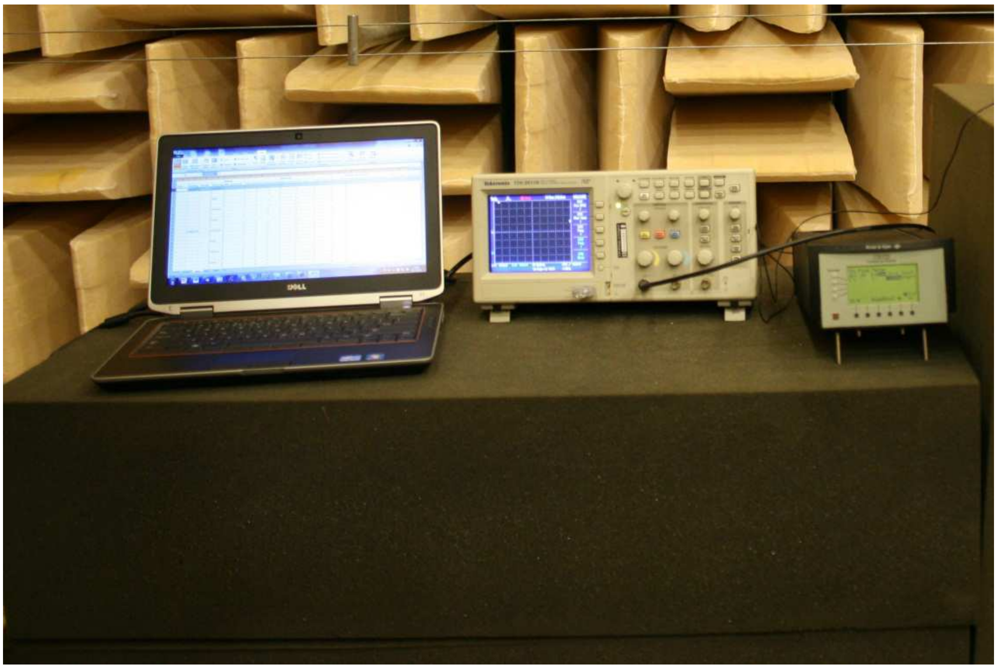

Figure 2 Measurement setup.

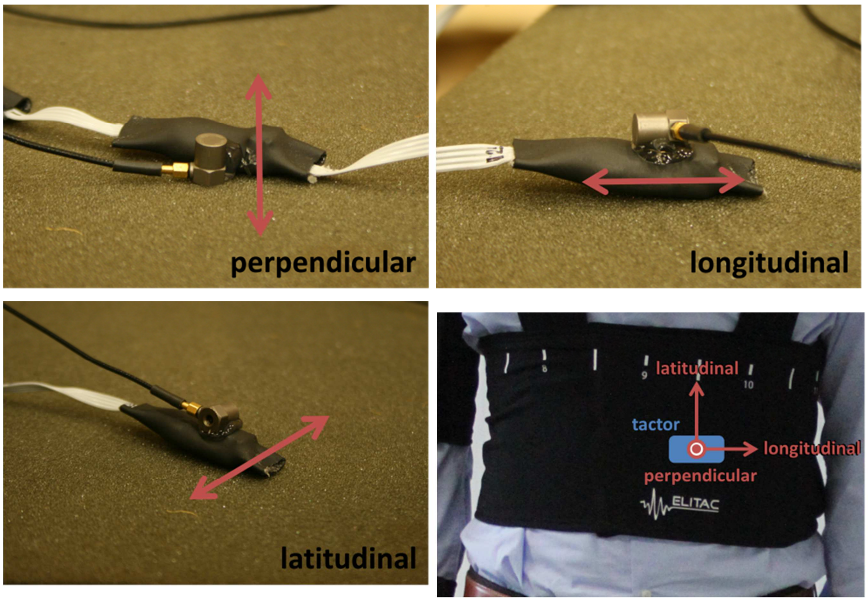

Figure 3 The different orientations of the accelerometer relative to the long axis of the tactor. During the measurements the top of the tactor - here in view - was facing away from the body and the long axis of the tactor was in the transverse plane of the human body as shown in the fourth picture. From left to right and top to bottom: perpendicular, longitudinal and latitudinal orientation.

2.2 Measures

To stay close to the conditions the tactile display will be used in, the following independent variables were used:

Table 1 Independent variables list.

Variable	Description	Reasoning
Tactor	3 different tactors on the same string were measured.	Variability among the tactors is expected.
Vibration direction	The vibration measurements were done in 3 different orientations: perpendicular, longitudinal and latitudinal.	It is expected that the coin motors vibrate more in the longitudinal and latitudinal direction then the perpendicular direction, because the way they rotate and because they are less restricted by the textile in these directions.
Vibration level	The 3 strongest vibration strengths of the 4 available levels were used.	The vibration level directly controls the rotational speed of the vibration motors.
Mechanical load	The vibration measurements were done under three different mechanical loads by stretching the textile around the waist: unloaded (textile was not stretched), 7% stretch and 15% stretch. The markings on the textile were used to determine the amount of stretch. The exact relationship between stretch and mechanical load is unknown.	The rotational speed of the vibrator motors is expected to depend on the mechanical load.

The procedure was as follows: The accelerometer was glued to the tactor in the desired direction and the tactor was pressed to the skin with the elastic textile with the desired stretch. Then the tactor was switched on at the desired strength with the laptop. When it had reached steady state, the amplification of the acceleration signal was set such that overload was just avoided. The resulting acceleration waveform was displayed on the oscilloscope, which was adjusted such that approximately 10 cycles fitted on the screen and that the amplitude of the signal equalled 2 to 4 divisions on the screen. Then the acceleration waveform was recorded to the USB stick and the root mean squared acceleration and fundamental frequency as indicated by the oscilloscope were noted down. Also the sound level was measured with the sound level meter at a distance of 10 cm. In the case the tactor was being activated at full strength and the acceleration was being measured in the perpendicular direction, the acceleration waveform on the oscilloscope was also recorded to the USB stick when the vibration motor started up and when it stopped. The oscilloscope was set such that in both cases both zero acceleration and full power were visible on the screen. From these recordings, the following dependent measures were derived:

Table 2 Dependent measures list.

Measure	**Symbol**	**Unit**	**Definition**	**Condition**
RMS acceleration	a_{RMS}	m/s^2	The root mean squared of the acceleration waveform in either one of the 3 vibration directions.	Only during steady state.
Resultant RMS acceleration	$a_{RMS,res}$	m/s^2	The root mean squared of the acceleration waveform in all vibration directions summed like orthogonal vectors.	Only during steady state.
Fundamental frequency	f_0	Hz	The estimated fundamental frequency of the acceleration waveform.	Only during steady state.
Total dynamic distortion	THD	%	The ratio of the power of the complete acceleration waveform to the power in the fundamental frequency. Smaller values mean that the signal resembles a sine function better.	Only during steady state.
Sound pressure level	p	dBA	A-weighted sound pressure level at 10 cm from the tactor.	Only during steady state at maximum vibration level in case of a perpendicular vibration direction.
Spin-up time	$t_{spin\text{-}up}$	ms	The time it takes for the tactor to go from a vibration power of -20 dB under the maximum (a factor 100 lower) to 0 dB (the maximum).	Only during spin-up to maximum vibration level in case of a perpendicular vibration direction.
Spin-down time	$t_{spin\text{-}down}$	ms	The time it takes for the tactor to go from a vibration power of 0 dB (the maximum) to -20 dB.	Only during spin-down from maximum vibration level in case of a perpendicular vibration direction.

3 Results

From each measure the main effects of vibration direction, vibration level and mechanical load were determined (if applicable). If there is a main effect, the mean values are plotted and tabulated. 95% confidence intervals of the means (CIs) are estimated using 1.96 times the standard error of the mean.

Multivariate ANOVA shows that the RMS acceleration does not depend on the mechanical load, but is does depend on both the vibration level ($p<0.001$; $F=28.72$) and direction ($p<0.001$; $F=67.84$). It becomes clear that the tactor vibrates more in the longitudinal and latitudinal direction then the perpendicular direction.
Overall, the tactor can vibrate the easiest in the latitudinal direction.

Table 3 Mean a_{RMS} and the 95% confidence interval for vibration level and direction, collapsed over tactor and mechanical load.

Vibration level	**Vibration direction**	**N**	**Mean a_{RMS} (m/s^2)**	**95% CI**
1	perpendicular	9	4.3	1.2
1	longitudinal	9	10.4	2.5
1	latitudinal	9	22.7	3.1
2	perpendicular	9	7.2	2.1
2	longitudinal	9	23.7	6.5
2	latitudinal	9	32.1	5.5
3	perpendicular	9	9.0	2.6
3	longitudinal	9	38.4	6.9
3	latitudinal	9	39.1	6.2

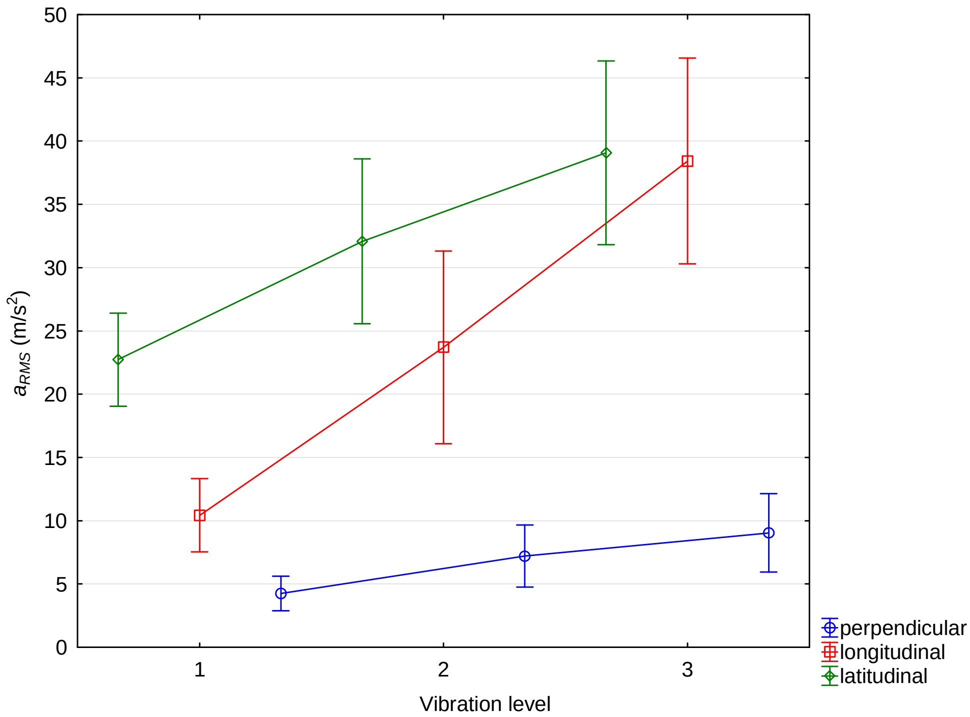

Figure 4 Mean a_{RMS} and the 95% confidence interval for vibration level and direction, collapsed over tactor and mechanical load (N=9).

The different directions can be combined to the resultant RMS acceleration ($a_{RMS,res}$), by summing them as vectors:

Table 4 Mean $a_{RMS\ res}$ and the 95% confidence interval for vibration level and direction, collapsed over tactor and mechanical load.

Vibration level	**N**	**Mean $a_{RMS,res}$ (m/s^2)**	**95% CI**
1	9	25.4	4.0
2	9	40.5	8.5
3	9	55.5	9.5

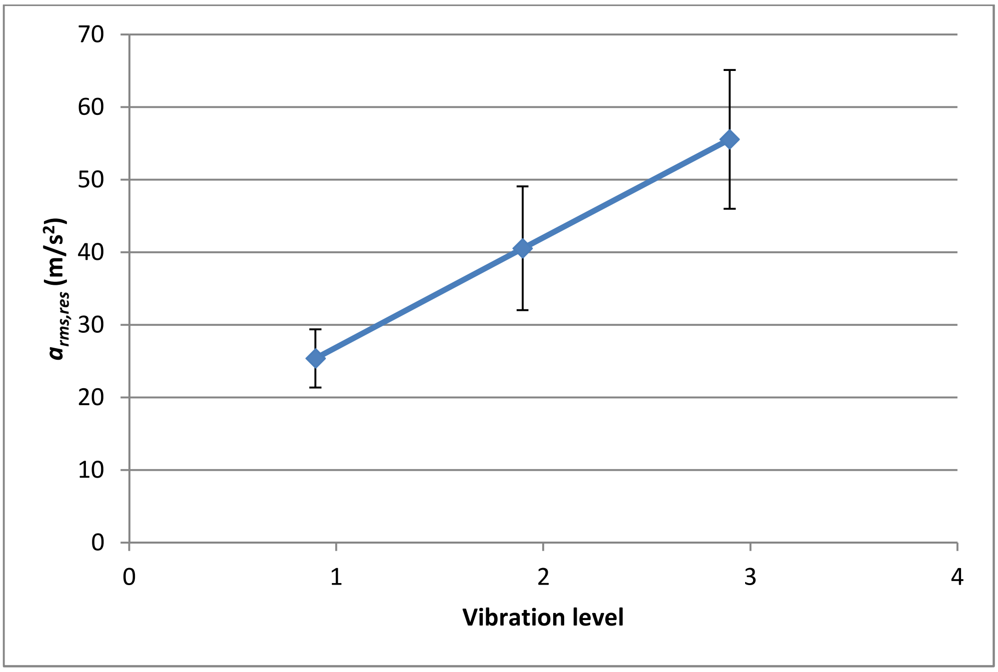

Figure 5 Mean $a_{RMS,res}$ and the 95% confidence interval for vibration level and direction, collapsed over tactor and mechanical load (N=9).

Multivariate ANOVA shows that the fundamental frequency does not depend on the mechanical load and vibration direction, but is does depend on the vibration level ($p<0.001$; $F=301.54$).

Table 5 Mean f_0 and the 95% confidence interval for vibration level collapsed over vibration direction, tactor and mechanical load.

Vibration level	N	Mean f_0 (Hz)	95% CI
1	27	111.6	3.7
2	27	138.7	2.1
3	27	158.3	2.4

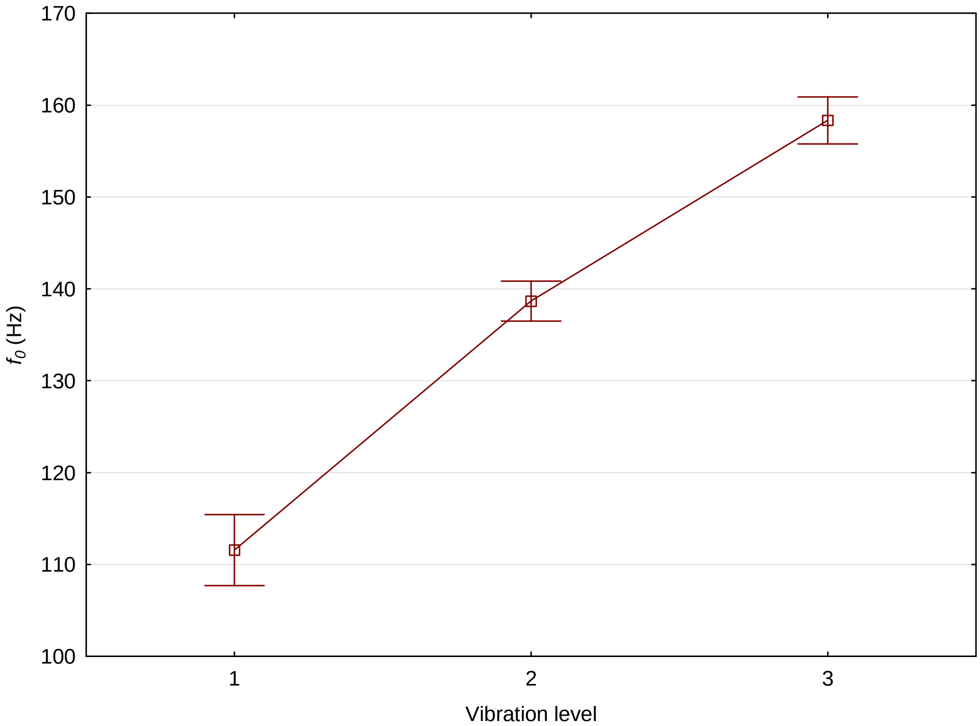

Figure 6 Mean f_0 and the 95% confidence interval for vibration level collapsed over vibration direction, tactor and mechanical load (N=9).

Multivariate ANOVA shows that the total dynamic distortion does not depend on the mechanical load and vibration level, but is does depend on the vibration direction ($p<0.001$; $F=31.29$). The distortion is much lower in the longitudinal and latitudinal direction then in the perpendicular direction.

Table 6 Mean *THD* and the 95% confidence interval for vibration direction collapsed over vibration level, tactor and mechanical load.

Vibration direction	**N**	**Mean *THD* (%)**	**95% CI**
perpendicular	27	4.5	1.4
longitudinal	27	0.61	0.13
latitudinal	27	0.42	0.08

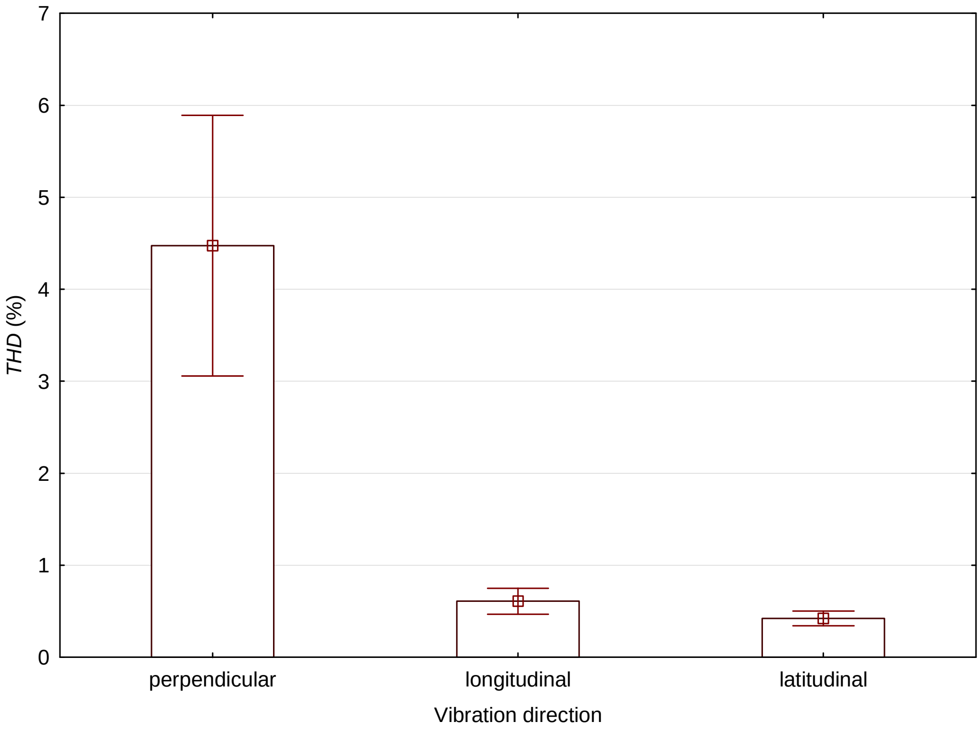

Figure 7 Mean *THD* and the 95% confidence interval for vibration direction collapsed over vibration level, tactor and mechanical load (N=27).

Univariate ANOVA shows that the sound pressure level does not depend on mechanical load.

Table 7 Mean *p* and the 95% confidence interval collapsed over mechanical load and tactor.

N	**Mean *p* (dBA)**	**95% CI**
9	47.7	2.3

Univariate ANOVA shows that the spin-up time does not depend on mechanical load.

Table 8 Mean $t_{spin\text{-}up}$ and the 95% confidence interval collapsed over mechanical load and tactor.

N	**Mean $t_{spin\text{-}up}$ (ms)**	**95% CI**
9	114	26

Univariate ANOVA shows that the spin-down time does not depend on mechanical load.

Table 9 Mean $t_{spin\text{-}down}$ and the 95% confidence interval collapsed over mechanical load and tactor.

N	**Mean $t_{spin\text{-}down}$ (ms)**	**95% CI**
9	75	8

Note that the spin-down time is shorter than the spin-up time and has less variability.