

# Evaluation of a sitting aid: the Back-Up

P. Vink\*, M. Douwes\* and W. van Woensel\*\*

\*TNO Institute of Preventive Health Care, Department of Posture and Movement Research. PO Box 124. NL-2300 AC Leiden, The Netherlands

\*\*University of Leiden, Interdepartmental Research Group of Kinesiology, Mezenstraat 2a, NL-2333 VT Leiden, The Netherlands

**The effects of a portable back support, the Back-Up, were tested in 28 variables. Both subjective and objective physical load measures were recorded during sitting with and without Back-Up, most of them during VDU work. The main result was that the posture of the upper back and neck/head was improved by the Back-Up. However, the knee straps induced unacceptable high pressure and increased significantly the discomfort in the legs. Based on these results the Back-Up was modified: the contact area between the strap and the knee was enlarged. This modified Back-Up was tested again for 13 variables with 10 new subjects. The knee pressure turned out to be acceptable and the discomfort was equal to sitting without the Back-Up. Based on this research the Back-Up is considered as a possible addition to more fundamental ergonomic improvements such as adjustable furniture and variation between sitting, standing and walking tasks, especially for improvement of the neck load. However, the Back-Up should not replace proper ergonomic workstation and work organization design or a backrest on the chair. Furthermore, the Back-Up should not be made obligatory, and it should be worn only for a part of the day, because it limits variation in postures.**

Keywords: musculoskeletal disorders, electromyography, office work, VDU work, back load, back support

In the Netherlands, 37% of VDU workers report musculoskeletal complaints in the neck and back at least once a week (Voskamp, 1991). To reduce musculoskeletal disorders in office work the TNO Institute of Preventive Health Care is developing a preventive approach. The approach consists of:

- a needs assessment questionnaire;
- a video film to stimulate awareness of the relationship between work and musculoskeletal injuries;
- a checklist to be used by employees to choose optimal improvements;
- different products, which can be tested by the workers; and
- training of key persons, who can guide the process of implementation and maintain or improve the situation in the long run.

Next to fundamental changes such as variation in tasks, products such as adjustable furniture, screen holders, reading desks, and manuscript holders are part of the approach.

In addition, a new product has become available: the Back-Up. The Back-Up is a portable back support, consisting of a back pad around the lower part of the back, which is connected to two straps around the

knees. Thus the Back-Up exerts a force on the lower back and the knees (Figure 1).

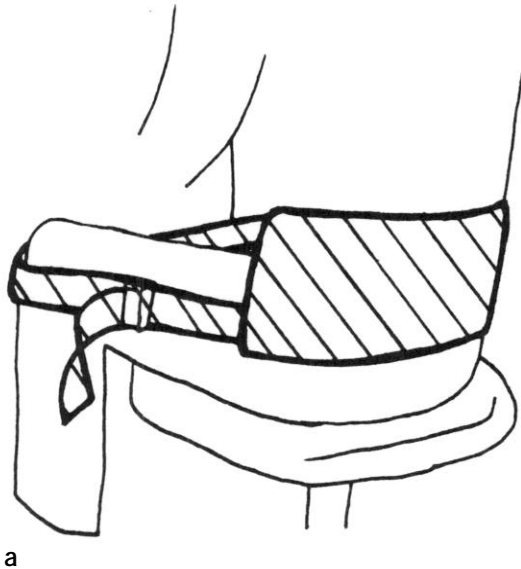
The question is whether this Back-Up can help to prevent musculoskeletal disorders. As VDU work has become a routine activity, the effect of the Back-Up was tested during this type of work. The research question is: is there an effect of wearing the Back-Up during VDU work on the load on the back, neck and knee compared with sitting without the Back-Up, and how is the Back-Up experienced by the users?

## Method

Subjective as well as objective measures were taken during sitting, with and without the Back-Up. Two experiments were carried out. In the first, back and neck muscle activity and force in the straps of the Back-Up were measured sitting with a large variety of back loadings. In the second experiment objective and subjective posture recordings were made during VDU work.

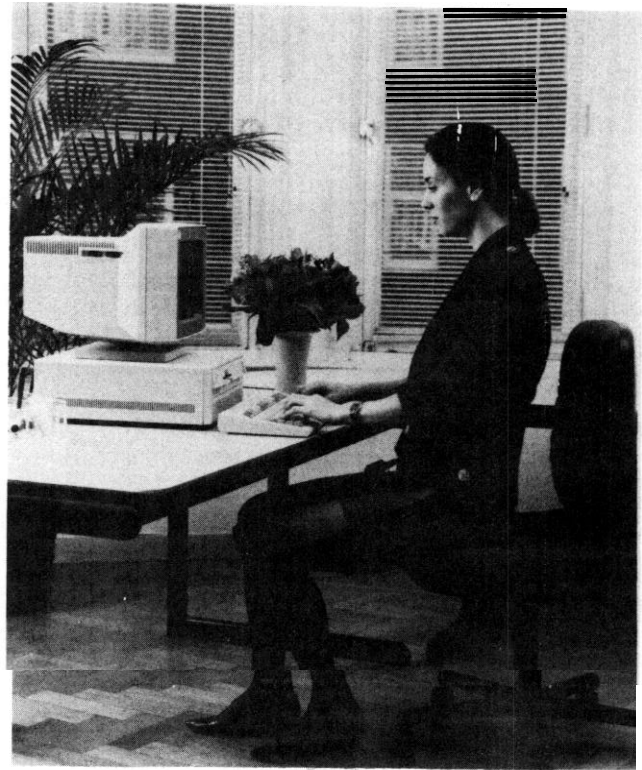
### *Back and neck muscle activity*

During sitting on a chair without back support the activity levels (EMG) of back and neck muscles were



a

Figure 1 The Back-Up: (a) schematic drawing and (b) in use



b

recorded with and without Back-Up. It would be most desirable to record activities during VDU work. Unfortunately, EMGs are influenced by the posture changes that accompany VDU work. EMG can only be used as a measure of relative muscle load within a certain posture. Therefore a standardized posture is required.

Two healthy men participated in this study (weight 65 and 73 kg; age 26 and 27 years; height 1.68 and 1.82 m, respectively). One week before the tests the subjects were given the Back-Up and they were instructed to wear it three times for an hour. In the tests RA-EMG (= rectified and averaged electromyograph) was recorded bilaterally with 12 pairs of surface electrodes (Figure 2). Recordings were made during sitting upright without back support with a knee angle of 90°. The extended arms were kept horizontally forward. In this posture the subjects had to hold weights of 0.6, 1.5, 2.4 and 3 kg, respectively, for 10-15 s with two hands. For subject 1, measurements were first performed without, and afterwards with, Back-Up. For subject 2 this was done the other way around. The EMG was rectified and averaged over 5 s (= RA-EMG) according to a procedure described in detail by Vink *et al* (1989). The mean differences in RA-EMG between sitting with and without Back-Up were calculated for each of the six electrodes. Thereby the RA-EMG was averaged over sitting with the six loadings and over the two subjects. Furthermore, the six electrodes on each body half were averaged (electrode C7 left with electrode C7 right, etc).

#### Knee loading

During sitting in the Back-Up the knee is loaded, because the straps around the knee pull the knee backwards. The acceptability of two different aspects of this load were studied for the two subjects used earlier: the load on the cruciate ligaments, and the compression of tissue between the bone (tuberositas tibiae) and the strap of the Back-Up.

The force on the knee was measured during EMG recording and related to literature values. A force transducer (S-cell Penko) was adapted to transform the force in the straps of the Back-Up into an electric signal. This signal was shown on a display unit (PNN Penko). For this purpose the right lateral strap of the Back-Up was cut and a force transducer was inserted in series with the strap.

Literature with reference values was searched in the files of:

- ≪≪ the International Occupational Safety Health Information Centre of the ILO, Geneva (CISDOC);
- ≪≪ the National Institute for Occupational Health and Safety (USA) (NIOSH); and
- ≪≪ the Health and Safety Executive Information Centre (UK) (HSELINE).

The search keywords were 'knee or knees or kneeling' and 'load or loads or loading'; 'ligament or ligaments or ligamentum' and 'knee'; 'pressure or compression' and 'tibia or tibiae'; 'knee' and 'pressure or compression' and 'tibia or tibiae'.

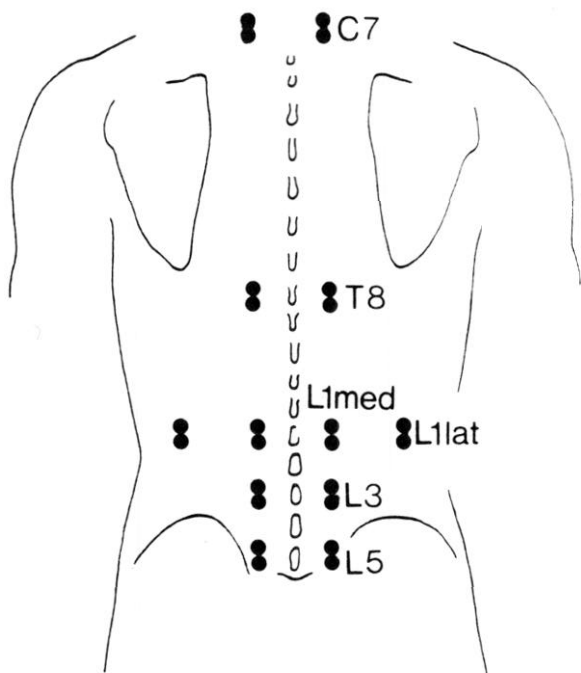


Figure 2 The position of the 12 pairs of surface electrodes

#### Posture of head and trunk

The head and trunk posture were measured with the opto-electronic Vicon system. This system includes retro-reflecting markers, which are attached to the body and reflect light transmitted by the cameras back into the cameras. Three-dimensional coordinates of the recorded markers were calculated with the help of a computer.

Eight markers were used (Figure 3) to establish the following angles:

- (1) the head angle (degree to which the head bends forward), defined as the angle between the median and the line connecting markers 1 and 2;
- (2) the neck angle (angle between head and trunk), defined as the angle between the two lines connecting markers 1 and 2, and 3 and 4, respectively;
- (3) the overall trunk position, defined as the angle between the median and the line connecting markers 3 and 8;
- (4) the position of the thoracic spine, defined as the angle between the median and the line connecting markers 3 and 7;
- (5) the shape of the thoracic spine, defined as the angle between the two lines connecting the markers 3 and 4, and 4 and 7, respectively;
- (6) the position of the thoracic spine at T11, defined as the angle between the median and the line connecting markers 5 and 6;
- (7) the position of the lower back and pelvis, defined as the angle between the median and the line connecting markers 7 and 8.

The difference between mean angles during sitting, with and without Back-Up, were tested with the t-test for paired observations ( $p = 0.05$ ).

#### General fatigue

As a measure of general fatigue the number of macro-movements were recorded by a method used previously and reported by Meijst and Dul (1990). Macro-movements are defined as non-task-related, clearly observable movements such as shifting one's seat position, stretching, and scratching. These movements probably function to counteract fatigue by initiating a temporary change in muscular strain. The number of macro-movements was determined by observation from video recordings. Because of the apparent inter-individual differences in the 'need' for macro-movements, for each condition the number of macro-movements was normalized by dividing it by the total number of macro-movements made by that subject. The difference between these normalized macro-movements in each condition was tested with the t-test for paired observations ( $p = 0.05$ ).

#### Subjective experience

Different variables were studied to record subjective judgement of the Back-Up.

*Local postural discomfort.* Local postural discomfort of different body regions was recorded by a method described in detail by Grinten (1991). Subjects had to

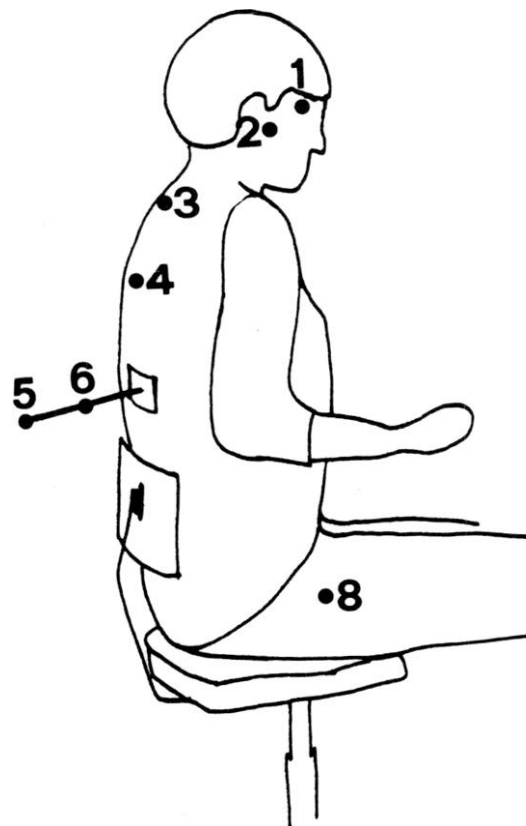
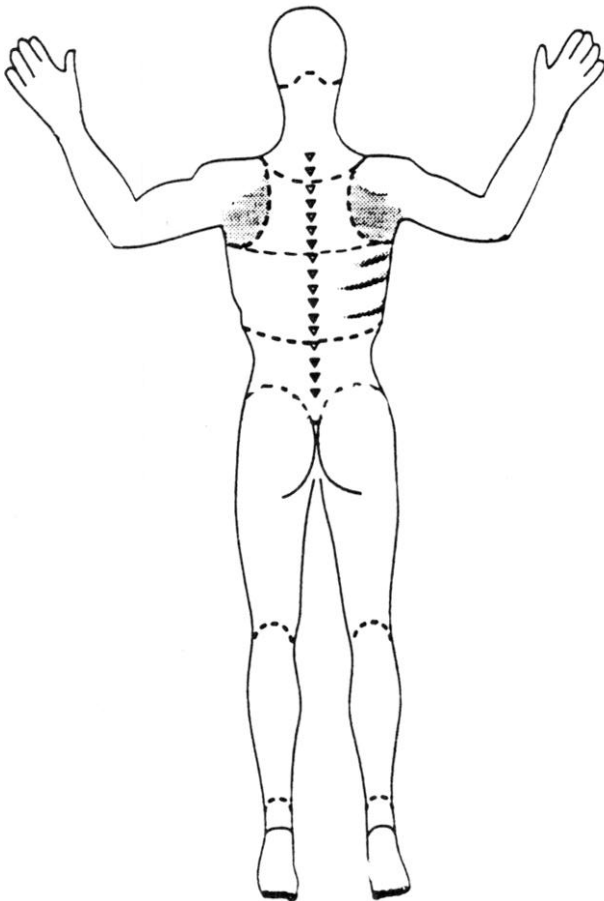


Figure 3 Positions of the markers to record the posture: 1, next to the right eye; 2, just next to the right ear; 3, on the spinal column at T1; 4, on the spinal column at T6; 5, 6, two markers on a bar perpendicular to the spinal column at T11 from which an imaginary point at T11 was calculated (7); 8, on the right hip (close to the trochanter major).

rate their experienced discomfort with a category ratio scale, ranging from no discomfort (= 0) to extreme discomfort (= 10), before and after sitting for work. A special form was used with a body diagram in which 40 body regions are marked (Figure 4). The 'before' scores were subtracted from the scores after the working period. Afterwards, out of the 40 regions seven clusters were formed by combining the results of regions. The differences between the two sitting conditions were tested by the Wilcoxon signed-rank test for paired observations ( $p = 0.05$ ).

*Perceived posture.* After each working period the subjects filled in forms to indicate how they perceived their posture in the upper back, lower back, neck and head. For the assessment of the perceived posture a seven-point scale was used (from 1 = very favourable to 7 = very unfavourable). The same statistical test as for discomfort was used.

*Estimated endurance time.* The subjects had to estimate for how long they could hold this particular posture on a five-point scale (from 1 = estimated endurance time of less than 30 min to 5 = could be endured for 112 to 1 working day). The same test as for discomfort was used to test the differences.



**Figure 4** Regions for rating the local postural discomfort on a scale from 0 to 10

*Final judgement.* At the end of the tests the subjects were asked whether they would rate their experience of wearing the Back-Up as very unfavourable, unfavourable, moderate, good or very good and whether they would wear the Back-Up if it was available within their company.

#### *Procedure and subjects*

In the second experiment the measured posture, local postural discomfort, perceived posture and other variables were recorded during a word-processing task by 10 healthy subjects (5 male; 5 female; mean age 26.8 years (sd 6.5); mean height 179 cm (sd 6.5); mean weight 70 kg (sd 10.1)), who had at least two years' experience with display work on a PC. Six subjects could touch-type well.

One week before the tests, the subjects were given the Back-Up and they were instructed to wear it twice during VDU work. Subsequent recordings were made during 1 h word-processing tasks with, and 1 h without, Back-Up with 10 min rest in between. Five subjects started with Back-Up and five without. Five subjects were tested in the morning and the other five in the afternoon. Before the test, their standing upright posture was measured twice with the optoelectronic Vicon system as a reference. It was assumed that a posture more similar to standing upright results in smaller biomechanical loads and is therefore preferable. Every second half-hour of the VDU work, ten Vicon recordings were made.

## **Results**

### *Back and neck muscle activity*

The RA-EMG differs at most by about 10  $\mu$ V between the conditions of sitting with and without the Back-Up; this is approximately 10% of the RA-EMG without Back-Up. In the neck and upper back, muscle activity is lower while wearing the Back-Up (Table 1). At lumbar level muscle activity is higher during wearing the Back-Up.

### *Knee loading*

The force recorded in one strap varied between 29 and 48 N. As there are two straps per knee, the straps of the Back-Up therefore pull the tibia backwards with a force of approximately 6-100 N. The literature survey found two studies concerning maximal forces on the cruciate ligament. Piziali *et al* (1980) describe how especially the posterior *cruciate ligaments* compensate this force. A force of 560 N on the lower leg in a backward direction was 93% absorbed by the posterior cruciate ligament. At 560 N the fibres remain intact. Noyes *et al* (1984) found that the posterior cruciate ligament ruptures under forces of around 1700 N. Therefore, with the force caused by the strap of the Back-Up, the knee ligaments will remain intact, although any long-term effects of course remain unknown.

The surface area over which the force of 60-100 N is distributed is about 2500 mm<sup>2</sup> (50 mm X 50 mm). The *compression pressure* between the straps and the tuberositas tibiae thus varies between 12 and 20 kPa. Two studies were found with skin pressure reference

**Table 1 Differences in RA-EMG averaged over the different loads, subjects and body halves. A positive difference in RA-EMG value means that the RA-EMG for sitting with Back-Up is lower**

Electrode	Value (µV)	sd
C7	+7.8	11.6
T8	+9.9	18.9
L1 lateral	-1.7	1.8
L1 medial	-0.7	2.9
L3	-2.4	5.0
L5	-6.4	6.6

values. Husain (1953) described how above 14 kPa irritation and redness of the skin develop. At an exposure time of longer than 2 h, subcutaneous oedema and inflammation of the skin and of underlying connective tissue occurs. More recently Holewijn (1990) stated that the skin pressure of a backpack below the shoulder blades may not rise above 10 kPa. Although more pressure is acceptable on the tuberositas tibiae of the lower leg than on the shoulder (Kirsch *et al*, 1980), it is preferable that the pressure should be in a safer range than the one found in this study.

*Posture of head and trunk*

The head and trunk posture during VDU work with the Back-Up is more similar to the standing posture than is that without Back-Up. The differences between angles are small (2° maximum), and only significant for the position of the head (Table 2).

*General fatigue*

The number of macro-movements is less during working with the Back-Up (mean difference 0.24 (sd 0.41),  $p = 0.094$ ), which gives some indication of less fatigue. However, this difference is not statistically significant and should be viewed with caution.

*Subjective experience*

*Local postural discomfort.* Postural discomfort in the neck, the upper back, and the middle and lower back is less during VDU work with the Back-Up than without, but this was not significantly different for the various regions (Table 3). If however the discomfort in the neck and the whole back are considered together, the difference between conditions is significant (difference 2.4 (sd 1.9),  $p < 0.003$ ), with Back-Up giving less discomfort.

For the upper and lower legs separately, as well as for both regions together, there is more discomfort after 1 h sitting with the Back-Up. This difference is significant ( $p < 0.05$ ) for the lower legs and the upper and lower legs together. This influence is so large that the sum of the reported discomfort for the whole body is higher (although not significantly) when the Back-Up is worn.

*Perceived posture.* There is almost no difference in perceived posture of head, neck and upper back during VDU work with and without the Back-Up (Table 4).

The posture of the lower back with Back-Up is judged significantly better than the posture without Back-Up.

*Estimated endurance time.* The subjects' estimates of endurance time is equal in both conditions (mean 1 - 2 h).

*Final judgment.* Six subjects judged the Back-Up as moderate, two as good and two as unfavourable. Two subjects indicated that they would wear the Back-Up occasionally if it were to be made available by their employer. Two subjects said they would only use it in case of back complaints or when tired. The other six subjects said they would probably not use it.

**Discussion**

To see whether there is an effect of wearing the Back-Up the results will be discussed by body region.

*Effects per body region*

The results of different variables and body regions are summarized in Table 5. This table shows that wearing the Back-Up during VDU work has positive effects in the neck region. A positive effect on the RA-EMG in the neck and a significant positive effect on the head posture is found and non-significant positive effects on local postural discomfort are found. The perceived posture is not influenced.

A positive tendency is also seen in the upper and middle region of the back. RA-EMG, posture and local experienced discomfort show a non-significant improvement and the perceived posture is not different.

On the lower back the effects are less unequivocal. In the lower back the RA-EMG is a little higher during

**Table 2 Mean differences in posture with and without Back-Up. A positive difference indicates an improvement of the posture when the Back-Up is worn.**

Posture variable	Difference (degrees)	sd
Head position	+1.9 <sup>a</sup>	2.5
Neck angle	+0.1	4.4
Overall trunk posture	+0.1	2.6
Thoracic back posture	+1.6	3.0
Thoracic back shape	+0.5	2.2
Back posture at T11	+1.1	3.2
Lumbar back/pelvis posture	+1.3	3.7

<sup>a</sup>Significant difference (t-test;  $p < 0.05$ )

**Table 3 Mean differences (n = 10) between the local postural discomfort with and without Back-Up. A positive difference means less discomfort when the Back-Up is worn**

Body region	Difference	Back-Up (min-max)	No Back-Up (min-max)
Neck	+0.5	0-2	0-2
Upper back	+0.5	0-3	0-6
Middle back	+0.8	0-2	0-6
Lower back	+0.7	0-1	
Upper legs	-2.2	1-14	0-6
Lower legs (and knees)	-2.1 <sup>a</sup>	0-4	0-0

<sup>a</sup>Significant difference (Wilcoxon signed-rank test;  $p < 0.05$ )

**Table 4** The difference in perceived posture ( $n = 10$ ). A positive difference means that working with the Back-Up is considered as favourable for the posture.

Body region	Difference	Back-Up (min-max)	No Back-Up (min-max)
Head	0	2-5	1-4
Neck	0	2-5	2-5
Upper back	0	2-5	2-5
Lower back	+1 <sup>a</sup>	1-3	3-5

<sup>a</sup>Significant difference (Wilcoxon signed-rank test;  $p < 0.05$ )

wearing the Back-Up, while the posture of the lower back is perceived to be significantly better. The increase in RA-EMG could of course be a spurious result but the procedure and equipment to measure muscle activity have been tested thoroughly (Vink *et al*, 1989) and can be regarded as reliable. Furthermore, the increase was shown in all cases with the different loadings. This could be due to the fact that the support feels good even though muscle activity increases. Another explanation is that the position of the muscles with respect to the electrodes is changed during work and activity of another part of the muscle is recorded. The posture of other body regions and local postural discomfort improved non-significantly.

As regards the legs, the pressure on the tissue is too high, because of the compression between the straps and the tuberositas tibiae. Also, the local postural discomfort in the lower legs was significantly higher when the Back-Up was used.

In conclusion, the Back-Up seems to have a positive effect on the posture of the upper back and neck/head and some effect on the low back. If the neck and the whole back are considered together, the discomfort is significantly less wearing Back-Up than without. However, the compression between the straps and the tuberositas tibiae should be less both with reference to recommendations in the literature and according to the discomfort in the legs. Only two subjects out of ten would use this Back-Up.

It was recommended that the contact area between the strap and the knee be enlarged, especially widening the pad on the knee. If, for example, the kneepad is 125 mm wide instead of 50 mm, the maximum pressure on the lower leg will be around 8 kPa, instead of the present 20 kPa, which is considered to be acceptable.

#### Testing a modified Back-Up

Based on these results Troy Special Products developed a knee cushion (Figure 5), which enlarged the contact

area between strap and tuberositas tibiae to 5000 mm<sup>2</sup>. The force in the strap, the local postural discomfort, perceived posture and judgements of the subjects were again measured with 10 new subjects. The subjects (5 male; 5 female; mean height 176.7 mm (sd 8.3); mean weight 66.2 kg (sd 9.1); mean years VDU experience 3.7 (sd 1.6)) performed a word-processing task for 1 h without back-Up, for 1 h wearing the 'old' Back-Up and for 1 h with the *modified* Back-Up, after first getting used to the Back-Up at home. The order of three conditions was systematically varied over the subjects.

The mean force in the straps of the modified Back-Up was almost the same as in the old Back-Up (Table 6). The maximum force (out of five measurements per condition for ten subjects) wearing the modified Back-Up was 45 N (see Table 6), which resulted in a pressure of 9 kPa, a pressure below the unacceptable level. The local postural discomfort on the lower legs/knees was the same during wearing the *modified* Back-Up and during sitting without Back-Up (Table 7). The local postural discomfort and perceived posture showed a similar tendency to that in the first experiment, especially the positive effects in the upper back and neck/head region. The perceived posture is non-significantly better in the head, neck, upper back and lower back, and the local experienced discomfort is non-significantly better in the neck and upper back. However, now the upper legs/bottom show only a non-significant higher discomfort, where this was significant in the previous experiment.

Six subjects said they would wear the *modified* Back-Up (two wanted to buy it) if it was available in the company, two would probably wear it, one would wear it only when it was obliged and one would probably not wear it. This is a much more favourable reception than for the original product.

#### Conclusions

This study indicates that the *modified* Back-Up has positive objective and subjective effects on the posture of neck and upper back and no unacceptable effects on other parts of the body for most subjects. These short-term effects indicate the possible usefulness of the Back-Up. For the lower back there are positive as well as negative effects.

Therefore the modified Back-Up is considered as a possible addition to more fundamental ergonomic improvements in VDU and similar work. However, the Back-Up is not a cheap and easy alternative to proper ergonomic workstation and work organization design.

**Table 5** The effect of the Back-Up on the different body regions and variables

Body region	EMG	Knee load	Measured posture	Postural discomfort	Perceived posture	Total
Head/neck	+		+ <sup>a</sup>	+	--	++
Upper/middle back	+		+	+	=	+
Lower back	-		+	+ <sup>a</sup>	+ <sup>a</sup>	?=
Legs		-				--

+ = Positive effect of the Back-up

- = Negative effect of the Back-up

<sup>a</sup>Significant difference (Wilcoxon signed-rank test;  $P < 0.05$ )

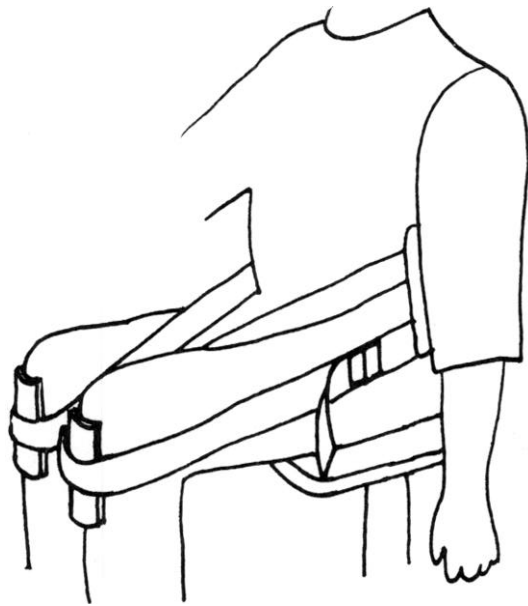


Figure 5 Knee cushion to enlarge the contact area between straps and tuberositas tibiae

Table 6 Recorded forces and estimated pressure on the knee wearing the modified and original Back-Up (n = 10)

	Original Back-Up	Modified Back-Up
Mean force (N)	19 (sd 9.9)	20 (sd 10.2)
Maximum force (N)	41	45
Mean pressure (kPa)	8 (sd 4)	4 (sd 2)
Max. pressure (kPa)	16	9

It should not replace more fundamental changes in the working environment such as better furniture, and job design in which walking, standing and sitting are varied. The Back-Up should also not replace a backrest on the chair, as it can only be worn during a part of the day.

However, prolonged VDU work is and will be needed in offices. For this work it is essential to have optimal work rest schedules (Dul *et al*, 1991) and an optimal posture. In addition, the Back-Up could be a worthwhile improvement if worn during a part of the day, to change the posture significantly, to one that is closer to standing and may be a welcome variation. It should not be worn for 8 h continuously, because of the lack of variation in posture. During wearing the Back-Up, RA-EMG in the low back will increase in situations with higher postural loadings than VDU work. It is therefore possible that during VDU work for the whole day this could give fatigue effects. This also supports the use of the Back-Up during a part of the day only.

Finally, although the Back-Up does have definite potential advantages there should be no attempt to make wearing it compulsory for three reasons.

(1) The long-term effects are unknown. In this study it is assumed that short-term positive effects, shown by different methods, in the neck and upper back region indicate a positive effect in the long term. However, the assumption that short-term effects predict long-term effects still needs to be proven.

Table 7 Mean differences (n = 10) between the local postural discomfort with and without the modified Back-Up. A positive difference means less discomfort when the modified Back-Up is worn

Body region	Difference	Back-Up (min-max)	No Back-Up (min-max)
Neck	+0.7	0-8	0-8
Upper back	+0.1	0-3	0-2
Middle back	+0.7	0-5	0-0
Lower back	+1.5	0-7	0-19
Upper legs	-2.7	0-11	0-27
Lower legs (and knees)	0	0-4	0-6

- (2) The positive effects found in this study may not be relevant to all employees, because of *interindividual variation*.
- (3) Another phenomenon that might give problems is the *social acceptability*. The appearance of the Back-Up doesn't invite one to wear it. Colleagues might find it strange. Only when one has worn it does one feel its advantages, and even when subjects have felt the advantages they could decide not to wear it because they find it strange. To avoid this problem, participation of employees in the choice of whether to wear the Back-Up is essential (Vink *et al*, 1992).

### Acknowledgements

The authors would like to thank Mr J. J. van Linschoten from Troy Special Products, Amsterdam, for making this research possible and M. Timmer-Anneveltd. W. A. Brand, W. Deegenars, H. Fraterman, B. Hyndman and H. Knijnenburg for their contributions.

### References

Dul, J., Douwa, M. and Smitt, P. 1991 'A work-rest model for static postures' in Quémec, Y. and Daniellou, F. (eds) *Designing for Everyone: Proc 11th Cong International Ergonomics Association* Taylor & Francis, London, pp 93-95

Grinten, M. P. van der 1991 'Test-retest reliability of a practical method for measuring body part discomfort' in Quémec, Y. and Daniellou, F. (eds) *Designing for Everyone: Pm 11th Cong International Ergonomics Association* Taylor & Francis, London, pp 54-57

Holewijn, M. 1990 'Physiological strain due to load carrying' *Eur J Appl Physiol* **61** 237-245

Husain, T. 1953 'An experimental study of some pressure effects on tissues with reference to the bedsore problem' *J Pathol Bacteriol* **66** 347-359

Kirsch, K. A., Merke, J., Ramon, N. and Wicke, H. J. 1980 'Tissue compliance in superficial tissues along body axis in man' *Eur J Appl Physiol* **38**, 239-244

Meijst, W. J. and Dul, J. 1990 *Research into the effects of fatigue in data-entry typists* Leiden, NIPG-TN0 (in Dutch)

Noyes, F. R., Keller, C. S., Grood, E. S. and Butler, D. L. 1984 'Advances in the understanding of knee ligament injury, repair and rehabilitation' *Med Sci Sports Exercise* **16** 427-443

Piziali, R. L., Seering, W. P., Nagels, D.A. and Schurman, D. J. 1980 'The function of the primary ligaments of the knee in anterior-posterior and medial-lateral motions' *J Biomech* **13**, 777-784

Vink, P., Daanen, H. A. M. and Verbout, A. J. 1989 'Specificity of surface-EMG on the intrinsic lumbar back' *Hum Mov Sci* **8** 67-78

Vink P., Lourijzen, E., Wortel, E. and Dul, J. 1992 'Experiences in participatory ergonomics: results of a round table session during the 11th IEA congress' *Ergonomics* **35**(2), 123-127

Voskamp, P. 1991 *Handboek ergonomie ('Manual ergonomics')*. Samson, Alphen (in Dutch)