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Effect of Four Computer Keyboards in Computer Users With Upper Extremity Musculoskeletal Disorders

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Eighty computer users with musculoskeletal disorders participated in a 6-month, randomized, placebo-controlled trial evaluating the effects of four computer keyboards on clinical findings, pain severity, functional hand status, and comfort. The alternative geometry keyboards tested were: the Apple Adjustable Keyboard™ [kb1], Comfort Keyboard System™ [kb2], Microsoft Natural Keyboard™ [kb3], and placebo. Compared to placebo, kb3 and to a lesser extent kb1 groups demonstrated an improving trend in pain severity and hand function following 6 months of keyboard use. However, there was no corresponding consistent improvement in clinical findings in the alternative geometry keyboard groups compared to the placebo group. Overall, there was a significant correlation between improvement of pain severity and greater satisfaction with the keyboards. These results provide evidence that keyboard users may experience a reduction in hand pain after several months of use of some alternative geometry keyboards. Am. J. Ind. Med. 35:647–661, 1999. *Published 1999 Wiley-Liss, Inc.*†

KEY WORDS: computer keyboard; musculoskeletal disorders; randomized clinical trial; office ergonomics; carpal tunnel syndrome

INTRODUCTION

With a rapid growth of computer usage in the workplace, considerable concern has been raised with respect to adverse health effects associated with computer use [Horowitz, 1992, Galen et al., 1992]. The incidence of upper limb musculoskeletal disorders (MSDs) related to computer use has appeared to increase steadily in the United States during the 1990s [Marcus and Gerr, 1996; Faucett and Rempel, 1994; Bernard et al., 1993]. According to the U.S. Bureau of Labor Statistics [1994], MSDs in the office sector more than doubled each year from 1988 to 1992. Significant associations between the number of hours of computer usage and MSDs have been reported in several epidemiologic studies [Bergqvist et al., 1995; Faucett and Rempel, 1994; Bernard et al., 1993; Burt et al., 1990]. Because exposure to computer input devices are becoming increasingly prevalent, risks associated with their use may have important public health implications.

The etiology of computer-related MSDs is not fully understood, but is suggested to be multifactorial, involving repetitive and forceful hand and finger exertions, awkward postures, prolonged hours of computer use, and work organization [Armstrong et al., 1993, 1994]. Several investigations have suggested that the conventional linear QWERTY keyboard designs may contribute to the development of MSDs by requiring users to assume arm and wrist postures of forearm pronation, ulnar deviation, and wrist extension during typing [Klockenberg, 1926; Kroemer, 1972; Duncan and Ferguson, 1974; Hunting et al., 1981; Seligman et al., 1984; Nakaseko et al., 1985]. As early as 1926 [Klocken-

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berg, 1926], alternative geometry keyboard designs were proposed to minimize discomfort associated with typing by splitting the keyboard into right and left halves and tilting each half laterally to achieve neutral positions of the wrists and forearms. Following Klockenberg's proposal, laboratory studies of split geometry keyboards have demonstrated subjective user preferences for the alternative designs [Kroemer, 1972; Grandjean et al., 1981; Nakaseko et al., 1985; Cakir, 1995], decreased hand and arm pain [Nakaseko et al., 1985], reduced ulnar deviation [Grandjean et al., 1981; Nakaseko et al., 1985; Cakir, 1995], and decreased electromyographic activities in the forearm, neck, and shoulder muscles [Zipp et al., 1983; Gerard et al., 1994].

In recent years, renewed interest in the potential roles of alternative geometry keyboards in preventing MSDs has prompted the commercial development of a variety of alternative keyboard designs. These designs were developed to increase user's comfort and reduce possible postural risk factors related to typing. Laboratory studies based on short-term use of these alternative geometry keyboards, ranging from 10 min to 2 days, have shown mixed results. Decreased electromyographic activities of some forearm muscle groups with use of the split geometry keyboards have been observed in some studies [Thompson et al., 1990; Gerard et al., 1994], but not others [Fernstrom et al., 1994; Marek et al., 1992]. Wrist deviations (e.g., extension and ulnar deviation) and/or forearm pronation [Burastero et al., 1994; Rempel et al., 1995] have been found to be reduced on the split keyboard designs. Short-term (e.g., 2 days to 2 weeks) preference studies of asymptomatic subjects have failed to yield consistent results. Swanson et al. [1997] reported no significant differences in discomfort and fatigue between four altered geometry designs, while Cakir [1995] and Tittiranonda et al. [1998] reported favorable ratings for an adjustable split keyboard. To date, no long-term studies have investigated the efficacy of alternative geometry keyboards in reducing musculoskeletal discomfort and symptoms in computer users with hand pain.

The aim of the present study was to determine whether computer users with musculoskeletal disorders can gain health benefit from long-term use of alternative geometry keyboards. To achieve this aim, a 6-month study was carried out to assess improvements in clinical symptoms and upper limb function in subjects who used three alternative geometry keyboards in comparison to a control group who used a conventional linear keyboard.

METHODS

Study Design

This was a 6-month, prospective, observer-blinded, placebo-controlled, randomized clinical trial comparing four keyboard treatments in 80 subjects with carpal tunnel syndrome and/or tendonitis. Eligible subjects were assigned one of the three alternative keyboard designs or a conventional placebo by using a random permuted block method [Pocock, 1991] and were stratified on the basis of disorder type (carpal tunnel syndrome and tendonitis or tendonitis only). Therefore, at the start of the study, there were 4 treatment groups with 20 subjects in each group. Outcome variables included changes in physical examination findings, pain severity, comfort and hand functional status.

Subject Recruitment and Selection Criteria

Potential subjects were employees of the Lawrence Livermore National Laboratory (LLNL) with possible carpal tunnel syndrome (CTS) and/or tendonitis as determined by review of the LLNL workers' compensation injury and illness database. Subjects were eligible to participate if they were full-time employees who were employed on their current jobs for greater than 3 months and used a computer keyboard for 4 h/day or 20 h/week or more. None had been exposed to alternative geometry keyboards prior to the study. We excluded those with previous hand/wrist surgeries as well as those who had been diagnosed with these conditions more than 2 years prior to the review date.

Subjects who met our eligibility criteria were invited to participate in the study and asked to sign an informed consent in accordance with the guidelines of the LLNL Institutional Review Board of the Human Subjects Committee. All information obtained about the subjects was confidential and available only to the investigators. Individual findings were not released and subjects' identities were protected using identification numbers. The employees were never identified by name. All subjects were free to withdraw from the study at any time. Participants continued to receive medical care from their regular health care provider irrespective of their status in the study.

Standardized medical histories and physical examinations were administered by two nurse practitioners blinded to previous medical history. Criteria for possible Carpal Tunnel Syndrome were:

1. Symptoms of paresthesia, numbness, or tingling on the volar surface of digits 1–3;
2. Numbness, tingling, or decreased sensation in the hands with use of hands or with hands in an awkward posture;
3. Symptom duration of at least 1 week or occurred at least 20 times in the last year;
4. No acute major trauma to the hand, wrist or shoulder within the past year;
5. Positive Phalen's test or Tinel's sign [Hoppenfeld, 1976]; and

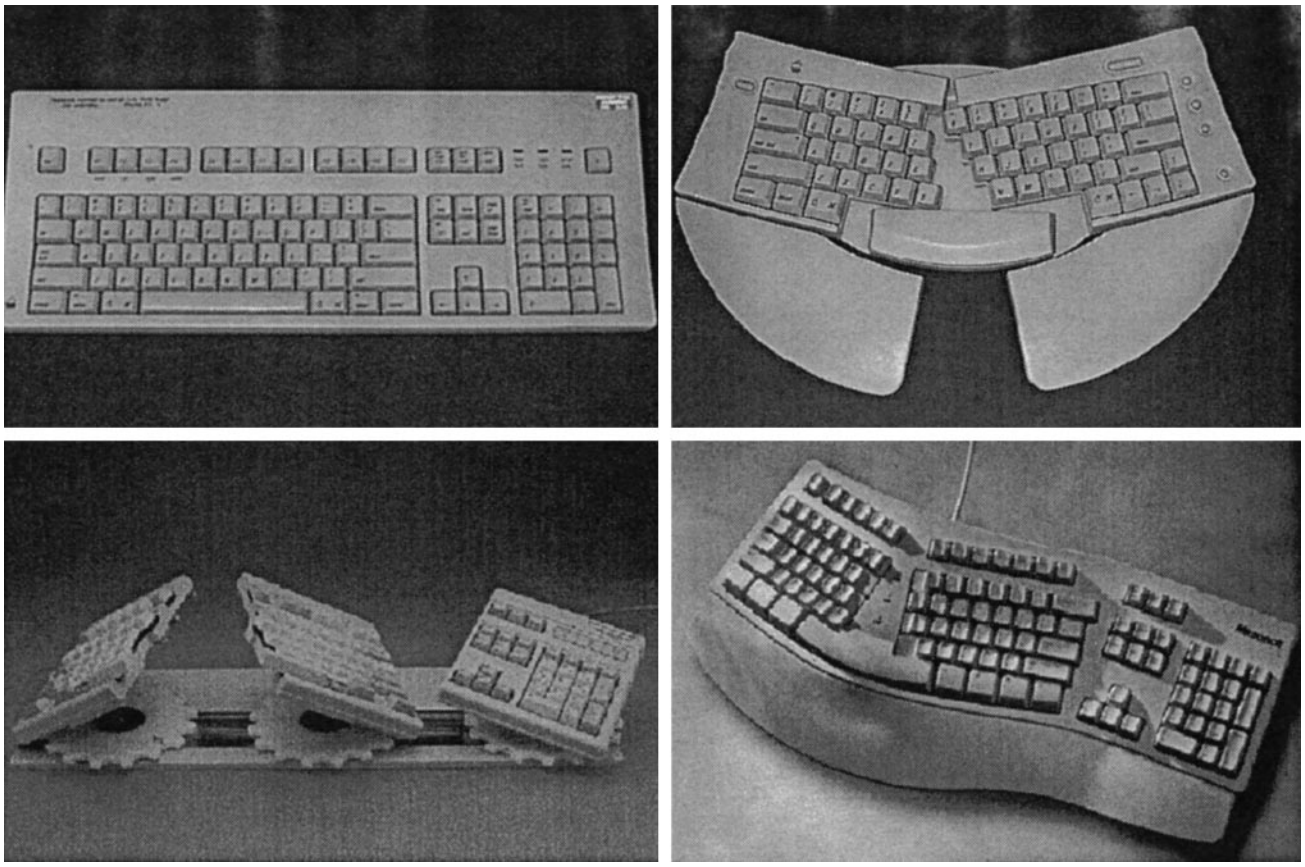

FIGURE 1. Four computer keyboards were used in the study: placebo (**top left**), kb1 (**top right**), the kb2 (**bottom left**), and kb3 (**bottom right**).

6. No evidence of thoracic outlet, cervical root or pronator teres syndromes on physical examination [Hoppenfeld, 1976]

Wrist or forearm tendonitis criteria:

1. Reported regional pain or swelling over the muscle-tendon structure of at least 1 week in duration
2. No history of major trauma to the hand and wrist
3. Physical examination evidence of one of:
   a. Positive Finkelstein's maneuver [Finkelstein, 1930], or
   b. Pain localized to specific extensor tendon(s) in distal ⅓ of dorsal forearm or wrist with passive wrist extension and palpation or active resistance to wrist or finger extension [Thorsen and Szabo, 1989; Chipman et al., 1991] with pain severity greater than 2 (symptoms were trichotomized as 1 = no pain, 2 = mild/moderate pain, and 3 = severe pain), or
   c. Pain localized to specific flexor tendon(s) in distal ⅓ of volar forearm or wrist with passive wrist flexion and palpation or active resistance to wrist or finger flexion with pain severity greater than 2 [Thorsen and Szabo, 1989; Chipman et al., 1991].

Keyboard Interventions

Eligible subjects were randomized to one of the four keyboard groups: Apple Adjustable Keyboard™ [kb1] (Apple Computer, Inc., CA) (n = 20), Comfort Keyboard System™ [kb2] (Health Care Keyboard Co., WI) (n = 20), Microsoft Natural Keyboard™ [kb3] (Microsoft, Corp., WA) (n = 20) or placebo (n = 20) (Fig. 1). The keyboard intervention was a supplement and not a replacement to routine medical care. Subjects in the study were undergoing active medical treatment, which included medication, physical therapy, and work restrictions.

The alternative geometry keyboards can be described by a coordinate system using axes of rotation for the two halves of the keyboard as follows: the first axis (α) is parallel to the tops of the home row keys, the second axis (β) lies in the plane of the keyboard surface and is perpendicular to the first axis, the last axis (γ) is perpendicular to the plane of the keyboard surface (Fig. 2). The configurations of the four keyboards are listed in Table I.

For subjects who were randomized to the placebo group, their own keyboard was taken to the ergonomics laboratory one week prior to the trial. At the laboratory, dust particles were expelled from the inner mechanism and outer

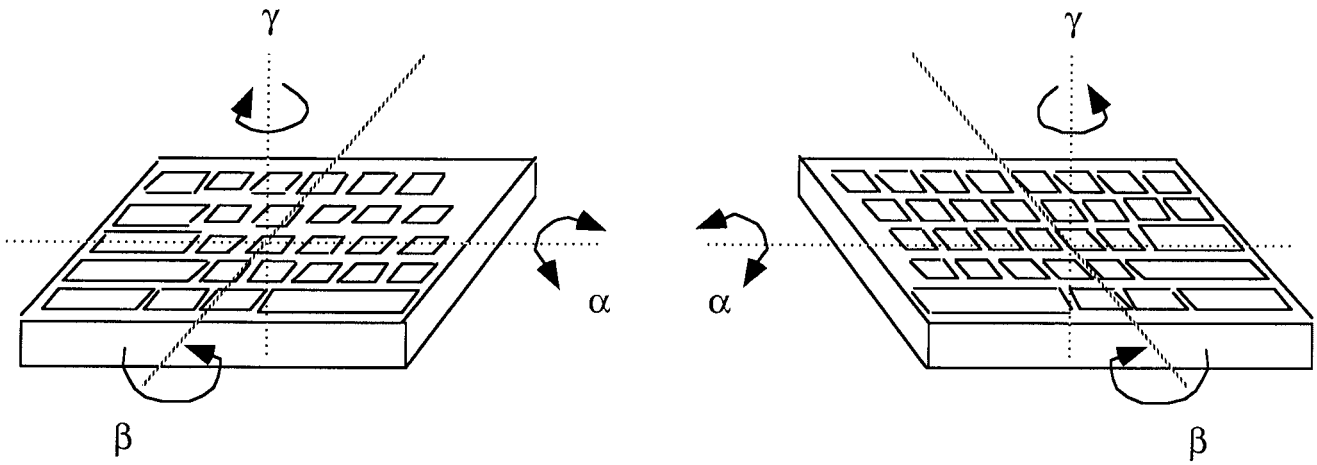

FIGURE 2. Axes of rotation of the keyboard surface halves. α = slope, β = lateral inclination, γ = opening angles.

TABLE I. Configurations of the Conventional Placebo and Split Geometry Keyboards*

	Keyboards			
	Placebo	**Kb1**[a]	**Kb2**[b]	**Kb3**
Slope (α)	8.0°	3.8° or 7.0°	−44.0° to +38.5°	5.5° or −2.6°
Lateral inclination (β)	0.0°	0.0°	0.0° to 90.0°	8.5° or 10.0°
Opening Angle (γ)	0.0°	0.0° to 28.0°	0.0° to 360.0°	12.0°
Distance between ''B'' and ''N'' keys[c]	2.0 cm	2.0 to 6.4 cm	2.0 to 36.0 cm	8.2 cm

*Placebo = Apple 101 Extended Keyboard; kb1 = Apple Adjustable Keyboard; kb2 = Comfort Keyboard System; kb3 = Microsoft Natural Keyboard.
[a]Function and number keys are located on a separate section containing similar lateral inclination and slope settings as the alphabetic section of the keyboard.
[b]Arrow and number keys are located on a third section containing similar slope, lateral inclination, and opening angle settings as the other two sections of the keyboard.
[c]Measured from center to center.

surface of the keyboards using compressed air. A label containing an alphanumeric identification number and a message that read ''This keyboard has been modified as part of an interventional field trial'' was attached to the left corner of the keyboard cover. An additional label which read ''This keyboard has been internally modified as part of the LLNL keyboard field study. Please do not attempt to repair or open it. If technical problems arise, call for immediate assistance'' was attached to the bottom of the keyboard. The screws underneath the keyboard platform were painted shut with blue-colored ink to prevent tampering. On the day of randomization, the keyboards were returned to the subjects and they were told that their keyboard had been ''modified'' in some way and that the researchers were blinded to the modification to comply with the study protocol.

All subjects were instructed to use the assigned keyboards in their workplace for 6 months. Additionally, they were told that the study involved evaluating the effects of various workplace and individual factors and not only the effectiveness of the computer keyboards. All participants received the same 1-h training session on office ergonomics aimed at risk factor identification and modification of furniture setup. Workstation adjustments were made on the day of randomization after which subjects were reminded periodically not to make further changes. Work site visits at mid- and post-intervention were made unannounced to ensure that adjustments to the workstations were not carried out by the subjects.

Outcome and Covariate Measures

Physical examination of the upper extremities was conducted for each participant at baseline and at the end of the 6-month trial. The examination was standardized and consisted of inspection, palpation, passive and resisted movements, and a series of provocative tests that included timed Phalen's, Tinel's, and Finkelstein's tests. The examiners were blinded to previous medical history and keyboard assignments.

Subjective outcome parameters included a self-administered questionnaire to assess hand/arm discomfort and pain severity as well as hand function, which were completed at baseline, and 6, 12, 18, and 24 weeks. Subjects rated the severity of their pain and discomfort in the upper limb and hand function during the previous week. In addition, they identified the body location and indicated the intensity of symptoms of stiffness, numbness or pain, using a series of 10-cm visual analogue scales (VAS). Ratings of hand function were based on the difficulty in performing activities of daily living (e.g., turning the doorknob, driving, writing, carrying milk carton, etc.) [Pransky, 1997; Levine et al., 1993]. At the end of the study or at the time of drop-out, subjects also compared various characteristics (e.g., feel and touch, keying mechanism, effort required when typing, hand/arm comfort, overall design, etc.) of their assigned keyboard to their usual, conventional keyboard. The comparison ratings were made on an 11-point VAS with verbal anchors. Detailed findings of long-term user preferences are published elsewhere [Tittiranonda et al., 1998].

To examine for confounding and covariate relationships, data on various factors identified from previous studies were collected. Data on psychosocial work stress, weight and height, anthropometry, and activity on the keyboard were collected at the beginning of the study using a long questionnaire and measurements. Psychosocial work stress factors were measured at baseline using the Job Content Instrument (JCI) [Karasek et al., 1981] and Work Interpersonal Relationships Inventory (WIRI) [Faucett and Rempel, 1994]. The two measures were designed to examine the effects of work stress on health. Three months into the study, subject weight and height were measured on a calibrated balance scale and anthropometric measurements (e.g., hand length, hand breadth, abdominal girth) were collected using electronic and body calipers. Keying activity was assessed by an Odometer Observer Software© (University of California San Francisco Ergonomics Program, CA). The software was installed on each of the participant's computer to continuously collect keying data for a 6-week period. Overall data collection schedule is shown in Table II.

TABLE II. Data Collection Schedule in Alternative Keyboard Study, Lawrence Livermore National Laboratory, 1994–1995

	Baseline		Study week			
	0		6	12	18	24
Medical history	x					
Psychosocial factors	x					
Physical exam	x					x
Overall pain severity	x		x	x	x	x
Regional symptom severity	x		x	x	x	x
Hand function	x		x	x	x	x
Keying activities	x	⟶	x			
Weight and height			x			
Anthropometry			x			
Keyboard user Preference						x

Statistical Analyses

Differences in baseline characteristics between keyboard groups were assessed by means of analysis of variance (and a comparable non-parametric Kruskal Wallis test) for continuous variables and Chi-Squared test of association for categorical variables ($P < 0.05$). Changes in outcome measures were calculated as the difference between the values at baseline and at the 6th month. For pain and symptom severity and hand function, if the 6-month data were missing due to subject's early withdrawal, the last rating was used in its place (e.g., last value carried forward [LVCF]) [Pocock, 1991].

Bivariate relationships between potential covariates (age, gender, hand anthropometry, body mass index, psychosocial stress factors, and hours of computer use) and outcome variables and between covariates and keyboard groups were investigated using linear regression analyses, Student's *t*-tests, and analysis of variance (ANOVA). A variable was considered to be a potential confounder if the statistical tests for the relationships between covariates and keyboard and between covariates and outcome variables showed $P < 0.10$.

Differences between the change in Tinel's Sign and Finkelstein's test in the three alternative keyboard and placebo groups were examined using chi-squared tests of associations ($P < 0.05$). Assessment of changes in Phalen's test time, overall pain level, regional symptom severity, and hand functional status were evaluated with the Kruskal-Wallis tests. The Kruskal-Wallis test is a non-parametric overall test of two-sided comparisons. Since only one-sided comparisons were of interest here, a significant difference at $P = 0.10$ or less was established as a criteria for performing posthoc multiple comparisons of the alternative keyboards to the placebo using the Dunnett's test (one-sided, mean $>$ control, $P < 0.05$). One-tail Dunnett's post-hoc procedures were used because we were interested in assessing significant improvement in the symptom and pain severity in those using the alternative keyboard groups as compared to the placebo controls. The distribution of subjects who showed a change in overall pain severity by an amount exceeding 25 and 50% of the baseline value was calculated for each keyboard group at 6 months. The temporal pattern of improvement in overall pain severity over the four intervals within the 6 months for the keyboard group was investigated using Repeated measures ANOVA ($P < 0.05$). A post-hoc Tukey-Kramer procedure ($P < 0.05$)

TABLE III. Mean Baseline Characteristics by Keyboard Group Assignments*

	Placebo (n = 20)	Kb1 (n = 20)	Kb2 (n = 20)	Kb3 (n = 20)	*P* values[a]
Demographic					
Age (yrs)	43.9 ± 8.2	44.8 ± 7.8	40.5 ± 9.7	45.4 ± 7.0	0.20
Gender = Female	13 (65)	10 (50)	11 (55)	12 (60)	0.86
Anthropometry					
Right hand length (cm)	18.5 ± 1.0	18.5 ± 1.2	18.4 ± 1.3	18.7 ± 1.4	0.84
Right hand breadth (cm)	8.6 ± 0.5	8.0 ± 0.9	8.4 ± 0.8	8.5 ± 0.9	0.16
Abdominal girth (in)	32.9 ± 6.5	32.1 ± 1.1	29.1 ± 1.1	30.7 ± 1.2	0.20
Body mass index (kg/m^2)	28.4 ± 7.1	31.0 ± 6.9	26.1 ± 4.4	27.6 ± 4.5	0.15
Computer use (hr/day)	3.0 ± 1.2	3.5 ± 1.3	3.5 ± 1.4	3.3 ± 2.3	0.62
Psychosocial stress					
High decision latitude	12 (60)	9 (45)	6 (30)	10 (50)	0.33
High psychological workload	12 (60)	11 (55)	11 (55)	9 (45)	0.93
High job satisfaction	15 (75)	13 (65)	12 (60)	5 (25)	0.02
Subjective health measures					
10 cm pain line	3.1 ± 2.2	3.1 ± 2.3	3.0 ± 1.8	2.6 ± 2.1	0.84
Overall functional status	2.2 ± 1.7	2.4 ± 2.1	1.7 ± 1.4	2.9 ± 1.9	0.30
Clinical measures					
Positive Phalen's test (right)	12 (60)	12 (60)	12 (60)	10 (50)	0.93
Positive Phalen's test (left)	6 (30)	9 (45)	5 (25)	6 (30)	0.56
Positive Tinel's sign (right)	2 (10)	7 (35)	4 (20)	4 (20)	0.26
Positive Tinel's sign (left)	1 (5)	7 (35)	4 (20)	3 (15)	0.10
Tendonitis Severity[b]					
Positive Finkelstein's test (right)	9 (45)	5 (25)	6 (30)	9 (45)	0.41
Positive Finkelstein's test (left)	4 (20)	1 (5)	4 (20)	5 (20)	0.34
EPL/EPB (right)	2.42 ± 0.7	2.80 ± 1.0	2.65 ± 1.0	2.60 ± 1.0	0.72
EPL/EPB (left)	2.43 ± 0.7	2.70 ± 0.9	2.34 ± 0.7	2.47 ± 0.8	0.71
ECU/FCU (right)	2.26 ± 0.5	2.75 ± 1.0	2.60 ± 0.7	2.50 ± 0.7	0.38
ECU/FCU (left)	2.21 ± 0.5	2.62 ± 0.9	2.38 ± 0.5	2.30 ± 0.5	0.45
EDC/ECR/LE (right)	2.52 ± 0.8	2.74 ± 0.7	2.73 ± 1.0	2.54 ± 0.6	0.50
EDC/ECR/LE (left)	2.44 ± 0.6	2.77 ± 0.9	2.22 ± 0.5	2.49 ± 0.7	0.12
FCR/ME/DF (right)	2.41 ± 0.6	2.96 ± 0.7	2.72 ± 0.8	2.69 ± 0.5	0.07
FCR/ME/DF (left)	2.36 ± 0.5	2.64 ± 0.6	2.25 ± 0.5	2.39 ± 0.5	0.14
No. of sites tendonitis					
Right (sites/subject)	2.65 ± 2.3	4.50 ± 3.1	3.25 ± 2.8	3.50 ± 2.8	0.30
Left (sites/subject)	2.40 ± 2.4	3.40 ± 3.1	1.80 ± 2.4	2.60 ± 2.9	0.39

*Mean ± standard deviations are given for continuous variables. The number of patients (with percent in parentheses) are given for categorical variables.

[a]*P* value between keyboard groups using Kruskal-Wallis test for continuous variables and χ^2 test for categorical variables.

[b]All subjects (N = 80) were diagnosed with tendonitis at some site. If more than one tendon is listed a row, the average values across tendon sites are reported. EPL = extensor pollicus longus, EPB = extensor pollicis brevis, ECU = extensor carpi ulnaris, FCU = flexor carpi ulnaris, EDC = extensor digitorum communis, ECR = extensor carpi radialis, LE = lateral epicondyle, FCR = flexor carpi ulnaris, ME = medial epicondyle, DF = digital flexors.

was used to determine if differences in pain severity between time periods and among keyboard groups were significant.

Categorical assessments of tendonitis severity were treated as continuous Likert scaled scores. Changes in tendonitis severity were calculated for four tendon/muscle groups: (1) extensors pollicis brevis and longus, (2) extensor/flexor carpi ulnaris, (3) extensor digitorum communis/carpi radialis/lateral epicondyle, and (4) digital flexors/flexor carpi radialis/medial epicondyle. For each tendon/muscle group, differences between keyboard groups were compared, using the Kruskall Wallis test. If $P \leq 0.10$, this was followed by post-hoc Dunnett's comparison of alternative keyboards to the placebo (one-sided, mean > control, $P < 0.05$). All analyses were carried out for each limb for all subjects and then for each disorder type separately (CTS and tendonitis and tendonitis only).

Spearman correlation coefficients were computed and tested for statistical significance ($P < 0.05$) to determine

whether overall rating of the assigned keyboards was associated with changes in the overall pain severity over time. Keyboard preference was trichotomized as ''worse'' than standard (0–3.67), ''same'' as standard (3.68–6.74), and ''better'' than standard (6.75–10); standard being the keyboard subjects used prior to the intervention. Two-way ANOVA ($\alpha = 0.05$) was performed to determine if ratings of overall pain significantly differ among the strata and among keyboards.

All data were verified for accuracy of entry. Analyses were performed with JMP Statistical Software version 3.1.6 (SAS Institute, Cary, NC) and SuperANOVA version 1.11 (Abacus Concepts, Inc., Berkeley, CA.).

RESULTS

Baseline Characteristics

Mean baseline demographic, anthropometric characteristics, duration of computer use, perceived psychosocial work stress, and clinical and health status for subjects by keyboard group are presented in Table III. Only one instance of substantial imbalance ($P < 0.05$) among the randomized groups was identified, indicating a relatively successful randomization process. Although a psychosocial factor was unevenly distributed between keyboard groups (e.g., a lower proportion of individuals who were highly satisfied with their job in kb3), linear regression analyses showed no significant relationships between this potential covariate and other outcome variables ($P > 0.1$). This variable is, therefore, not a covariate.

Subjects' mean right hand length and breadth were 18.5 and 8.4 cm, respectively. These values were comparable to the 50th percentile of hand anthropometric estimates for U.S. adults (18.7 cm hand length and 8.2 cm hand breadth for mixed male and female population) [Rodgers, 1983]. Mean body mass index (BMI) was 28.3 kg/m^2 which was slightly higher than the 50th percentile BMI for mixed gender U.S. adults (26.5 kg/m^2) [Rodgers, 1983]. Average time spent using the computer per day as recorded by the Odometer Observer software© was 3.3 h and was lower than the self-reported mean of 4 h or more per day. A majority of the participants reported high Decision Latitude and Psychological Work Load. Most reported high job satisfaction except for those assigned to kb3 ($P = 0.02$).

The mean baseline pain severity (0 = no pain and 10 = worst possible pain) and overall functional status (0 = not a problem and 10 = a very significant problem), 3.0 and 2.3, respectively, were not significantly different between keyboard groups. Phalen's test was positive on the right hand for 57% of the subjects, while 33% of the subjects exhibited a positive Phalen's test on their left hand. Positive Tinel's sign was observed on the right hand for 21% of the participants, and on the left hand for 19% of the participants.

TABLE IV. Reasons for Withdrawal From Intervention Trial by Keyboard Group

	Placebo (n = 20)	Kb1 (n = 20)	Kb2 (n = 20)	Kb3 (n = 20)
Worsening symptoms			1	
Broken wrist			1	
Keyboard mechanical failure			5	
Reduced productivity			2	
Lack of work space		1		
Lack of time commitment				1
Total dropouts	0	1	9	1

The percent who tested positive for the Finkelstein's test for the right thumb was 36 and 17% for the left thumb. The average number of positive tendon sites identified on the clinical examination were 3.5 per subject on the right limb and 2.6 on the left limb. The mean baseline tendonitis severity scores based on clinical examination ranged from 2.3 to 2.9 (1 = no pain, 2 = moderate pain, and 3 = severe pain) on the right and from 2.2 to 2.8 on the left.

Withdrawals

Eleven (14%) subjects withdrew from the study during the 6 months (Table IV). Withdrawals were most frequent in the kb2 group (n = 9); five of these were due to keyboard mechanical failure. One each withdrew from the other alternative keyboard groups. Reasons given for withdrawal were: frustration with their reduced productivity (n = 2, kb2) and increased discomfort (n = 1, kb2), inadequate workspace for use of detached numeric/function key pad (n = 1, kb1), and lack of time commitment (n = 1, kb3).

Arm and Hand Symptoms

Due to early withdrawal and missed appointments, data for 13 participants were missing at the 6-month follow-up visit and for these subjects, the last value carried forward (LVCF) method was applied to overall pain severity and hand function to control for ''survivor bias'' for the remaining analyses. Differences in the overall pain severity among all keyboard groups are shown in Table V. There was a significant trend of reduced overall pain severity in the alternative keyboard groups, with significant reductions in overall pain severity in kb3 at 6 months (1.21 ± 3.1) compared to the placebo group (-0.29 ± 1.5) (post-hoc Dunnett's test, one-sided, mean > control, $P < 0.05$). Further analyses of tendonitis (n = 36) and CTS (n = 44) subgroups showed that the corresponding decrement in pain severity at 6 months for kb3 was significant among those diagnosed with tendonitis (2.00 ± 2.3 vs. -0.28 ± 1.9 for

TABLE V. Changes in Overall Pain Severity Between Baseline and Sixth Months by Keyboard Group*

	Placebo	Kb1	Kb2	Kb3	*P* values[a]
All	−0.29 ± 1.5 (n = 20)	0.52 ± 2.0 (n = 20)	0.84 ± 1.9 (n = 20)	1.21 ± 3.1[b] (n = 20)	0.106
Tendonitis	−0.28 ± 1.9 (n = 9)	0.67 ± 1.6 (n = 9)	1.00 ± 1.2 (n = 9)	2.00 ± 2.3[b] (n = 9)	0.088
CTS	−0.29 ± 1.3 (n = 11)	0.41 ± 2.5 (n = 11)	0.68 ± 2.4 (n = 11)	0.50 ± 3.7 (n = 11)	0.573

*Value as mean ± standard deviations are given. Negative values indicate worsening of pain severity over time. Overall pain severity is rated as none at all (0) to worst imaginable (10).
[a]Significant if $P < 0.10$.
[b]In follow-up, mean significantly different from placebo ($P < 0.05$) using a one-tailed Dunnett's test.

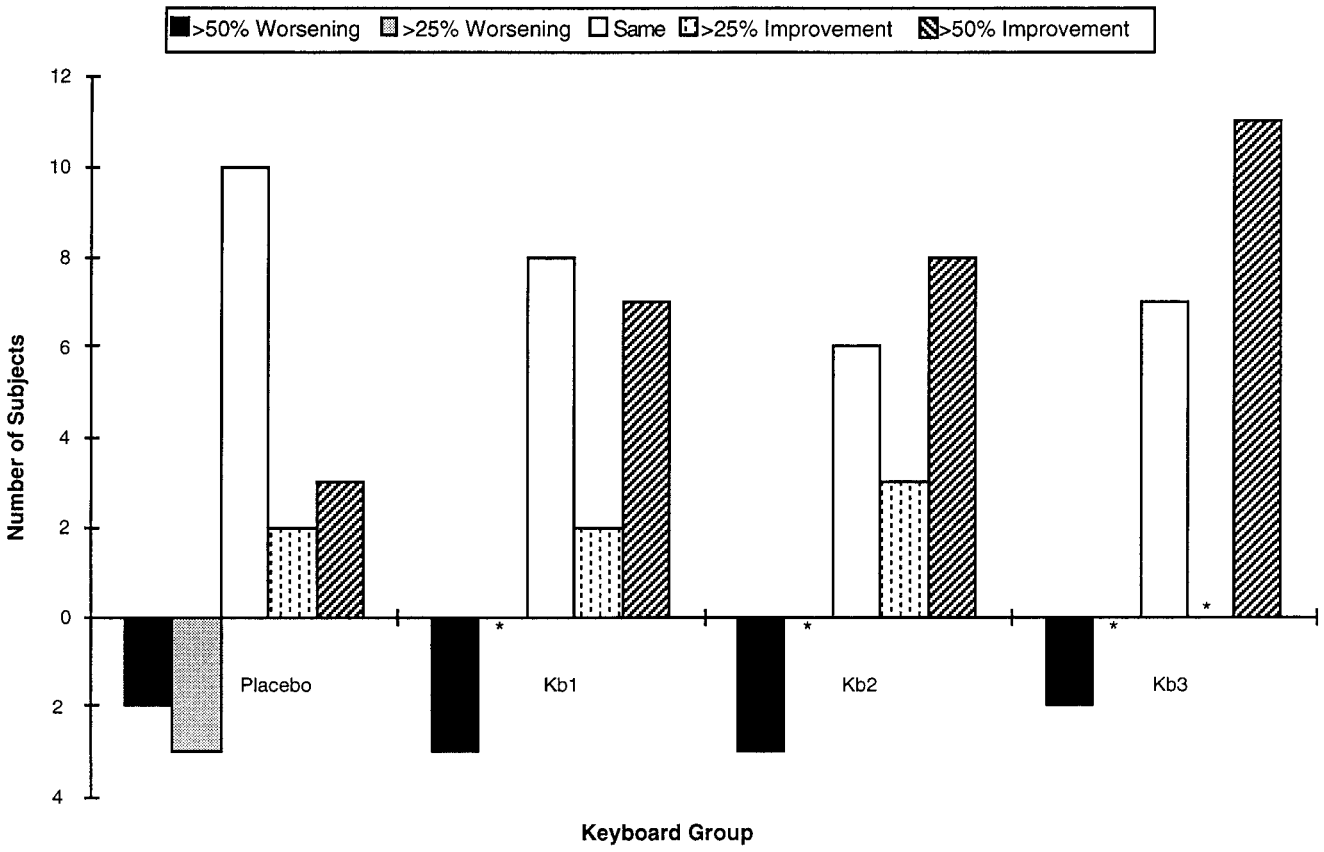

FIGURE 3. Number of subjects who reported improvement, worsening, or no change in overall pain severity from baseline to 6 months by keyboard group. *No subjects in this category.

the placebo) ($P < 0.05$), but was not for the CTS subgroup (0.50 ± 3.7) ($P > 0.05$).

The distribution of subjects who improved, worsened, or remained the same in overall pain severity at 6 months (or withdrawal) compared to baseline is shown in Figure 3. At 6 months, the number of subjects who reported substantial improvement (>50% change) in overall pain were greatest in the kb3 group (55%), followed by kb2 (40%) and kb1 (35%). For the placebo group, a majority of the subjects (50%) reported no changes in pain severity compared to 30% in kb2, 35% in kb3, and 40% in kb1. Moderate (>25% change) or substantial (>50% change) worsening in overall pain was reported by 25% of the placebo group, compared to 15% in kb1, 15% in kb2, and 10% in kb3.

The differences in the changes in severity of specific types of symptoms for the right and left upper limbs between

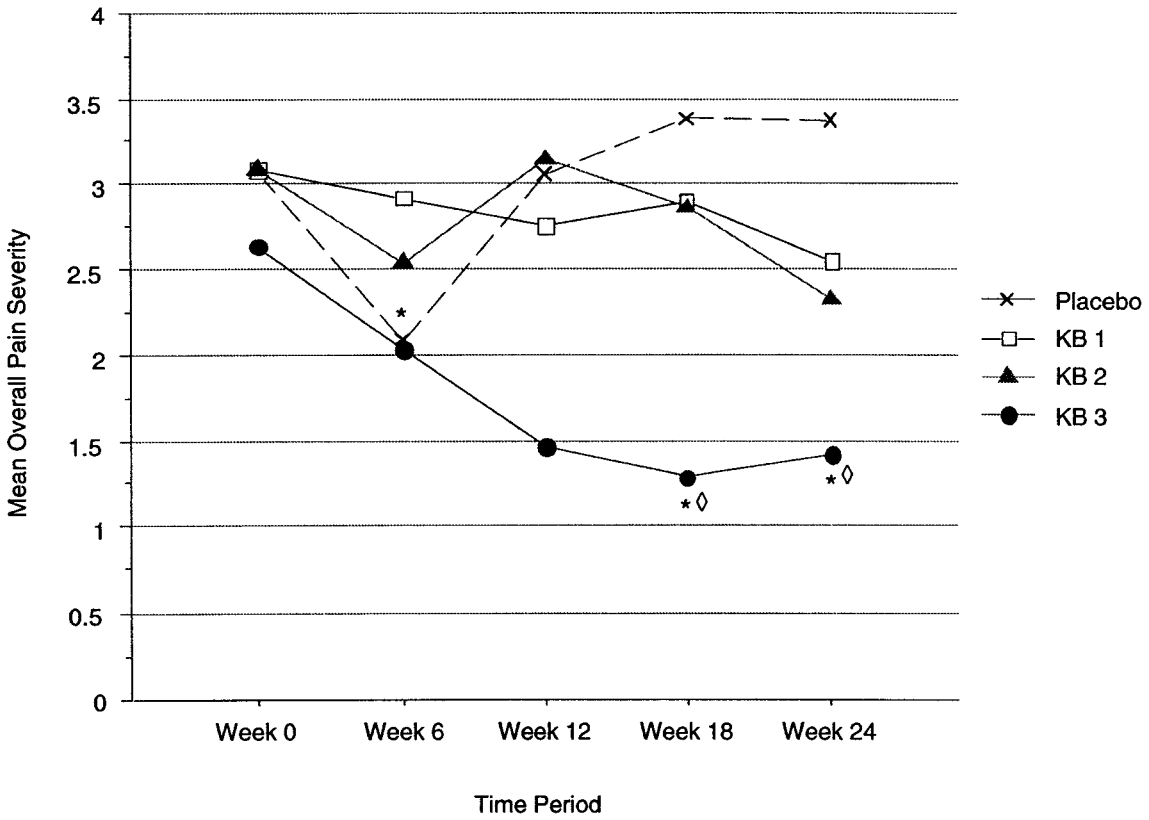

FIGURE 4. Changes in the mean overall pain severity measured during the intervention trial by keyboard group assignments. *A significant difference in mean overall pain severity between week 0 and follow-up time periods within a keyboard group using a posthoc Tukey-Kramer procedure ($P < 0.05$). ◇, a significant difference in mean overall pain severity between placebo and alternative keyboard groups at each time period using a posthoc Tukey-Kramer procedure ($P < 0.05$).

baseline and at 6 months were analyzed for all keyboard groups (data not shown). For the right upper limb, there was a positive, but not significant trend toward greater improvement in symptom severity dorsal forearm stiffness ($P = 0.45$), numbness ($P = 0.12$), and pain ($P = 0.62$) for kb1 and kb3. A post-hoc analysis of the tendonitis subgroup (n = 36) demonstrated that volar forearm stiffness significantly improved for kb3 (0.54 ± 1.1) in comparison to placebo (-0.40 ± 0.9) ($P < 0.05$). Tendonitis subjects who used kb1 (0.38 ± 2.2), kb2 (1.60 ± 2.1), and kb3 (1.30 ± 2.4) also reported decreases in finger numbness in the dorsal aspect of the right hand compared to the placebo group (-1.0 ± 2.1) who reported increases in symptom severity ($P = 0.04$). Such changes were significantly different when kb2 and kb3 were compared to the placebo group ($P < 0.05$). In addition, a significant improvement in hand and wrist numbness was observed among those who used kb2 (1.10 ± 1.3 vs. -0.40 ± 0.8 for placebo, $P < 0.05$). Evaluation of the CTS subgroup (n = 44), showed a significant reduction in volar forearm numbness and dorsal forearm pain at 6 months for kb1 (0.83 ± 1.7 vs. -0.15 ± 2.0 for placebo) and kb3 (1.60 ± 3.0 vs. -0.75 ± 1.5 for placebo) respectively ($P < 0.05$).

For the left upper limb, the kb1 group showed significant improvements at 6 months in volar hand and wrist pain (0.65 ± 1.7 vs. -0.34 ± 1.2 for placebo), dorsal pain in the fingers (0.50 ± 1.7 vs. -0.13 ± 0.5 for placebo), and forearm stiffness (0.60 ± 1.1 vs. -0.53 ± 1.1 for placebo), numbness (0.50 ± 1.6 vs. -0.19 ± 0.6 for placebo), and pain (0.70 ± 1.3 vs. -0.24 ± 1.0 for placebo) ($P < 0.05$). Kb3 group had significantly greater decreases in dorsal pain in the digits (0.50 ± 1.0 vs. -0.14 ± 1.3 for placebo) and stiffness in the forearms (0.36 ± 1.1 vs. -0.52 ± 1.1 for placebo) ($P < 0.05$). Kb1 group had significantly greater decreases in dorsal hand and wrist pain (0.58 ± 1.2 vs. -0.55 ± 1.0 for placebo) and forearm stiffness (0.75 ± 1.2 vs. -0.27 ± 1.3 for placebo) in the CTS subgroup. The effect of kb3 on the CTS subgroup was not significant.

Temporal Pattern of Pain Severity

Changes in overall pain severity by 6-week time periods by keyboard group are shown in Figure 4. Repeated measures ANOVA comparing the change in overall pain severity over time between keyboard groups was of borderline significance ($P = 0.06$). Each keyboard group demon-

TABLE VI. Changes in Functional Status Scores Between Baseline and Sixth Months Follow-Up by Keyboard Group*

Activities	Placebo (n = 20)	Kb1 (n = 20)	Kb2 (n = 20)	Kb3 (n = 20)	*P* values[a]
Turning a doorknob	0.02 ± 1.7	−0.13 ± 1.7	0.31 ± 1.8	0.97 ± 2.3	0.369
Hammering	−0.28 ± 1.6	0.36 ± 1.5	0.23 ± 2.3	0.62 ± 1.5	0.372
Sleeping	−0.09 ± 2.2	0.26 ± 1.4	−0.20 ± 1.5	0.10 ± 2.8	0.185
Writing	−1.09 ± 3.0	−0.05 ± 1.4	0.54 ± 2.3	1.48 ± 3.1[b]	0.038
Carrying milk carton	−0.21 ± 2.9	0.20 ± 1.5	0.23 ± 1.3	1.23 ± 3.0	0.358
Picking up small objects	−1.07 ± 2.3	−0.38 ± 1.4	0.39 ± 1.0	0.65 ± 2.4	0.206
Driving >30 min	−1.02 ± 2.4	−0.11 ± 1.6	−0.31 ± 0.9	1.57 ± 3.2[b]	0.038
Tying shoe laces	−0.06 ± 1.5	−0.16 ± 0.9	−0.22 ± 0.1	2.00 ± 3.0[b]	0.007
Performing jobs	−0.22 ± 2.5	0.35 ± 1.4	0.03 ± 2.6	2.00 ± 3.1[b]	0.103
Using a keyboard	−0.82 ± 2.4	0.54 ± 0.9[b]	0.07 ± 2.5	1.90 ± 2.9[b]	0.039
Housework	−0.24 ± 2.0	0.32 ± 1.7	0.60 ± 1.4	2.30 ± 2.4[b]	0.017
Overall score	−0.54 ± 1.3	0.39 ± 0.8	0.03 ± 1.0	1.38 ± 2.1[b]	0.005

*Mean ± standard deviations are given. Negative values indicate worsening of function over time. Changes in functional status scores are rated as no difficulty at all (0) to most difficult (10).
[a]Statistical significance between keyboard groups using Kruskal-Wallis test ($P < 0.10$).
[b]Mean significantly different from placebo ($P < 0.05$) using a one-tailed Dunnett's test.

strated a reduction in pain at 6 weeks, after which the mean pain scores reversed back toward baseline for kb2 and placebo, but continued to decrease for kb1 and kb3 at 12 weeks. For the placebo group, posthoc Tukey-Kramer procedure ($\alpha = 0.05$) indicated a significant pain decrease from baseline at 6 weeks for the placebo group, but no difference at later weeks. For kb3, the reduction in overall pain severity from baseline was statistically significant at 18 and 24 weeks for kb3 ($P < 0.05$). Within both of these time periods, overall pain severity for kb3 was significantly lower than the placebo group (post-hoc Tukey-Kramer procedure, $P < 0.05$).

Functional Status

Changes from baseline to 6 months in functional status for all keyboard groups are presented in Table VI. In general, consistent improvements in functional activities were demonstrated for kb3, while a decline in hand function was observed for the placebo. In comparison to the placebo group, the kb3 group experienced significantly less difficulties in writing ($P = 0.04$), driving greater than 30 min ($P = 0.04$), tying shoelaces ($P = 0.01$), performing current job ($P = 0.1$), using a keyboard ($P = 0.04$), and doing housework ($P = 0.02$), after 6 months of keyboard usage. The improvement in overall functional status score for kb3 (1.4 ± 2.1 vs. -0.5 ± 1.3 for placebo) at the 6-month follow-up visit was statistically significant ($P < 0.05$). Additional analyses revealed that the directional changes in the difficulties related to functional activities in the tendonitis and CTS subgroups were similar to the overall trend. For the kb1 group, a significant decrease in the difficulty associated with using a keyboard (0.5 ± 0.9 vs. -0.8 ± 2.4 for placebo) was observed ($P < 0.05$).

Clinical Outcomes

Changes in physical examination findings from baseline to 6 months are presented in Tables VII and VIII. Due to a high withdrawal rate (45%) for kb2, this group was excluded from the analyses of clinical outcomes. Overall, kb1 and kb3 groups showed no significant decrease in the prevalence of the Phalen's test, Tinel's sign, and Finkelstein's test, after 6 months of keyboard use. Among those who tested positive for Phalen's test, the average changes in Phalen's test time were similar across keyboards. Clinical status, based on Phalen's test, Tinel's sign, and Finkelstein's test remained unchanged for a majority of the participants after 6 months of keyboard use (i.e., those with positive tests remained positive and those with negative tests remained negative).

In general, alternative geometry keyboard groups demonstrated a positive, although not significant trend for improvements in severity within the 4 tendon categories. Improvements in tendonitis severity from baseline to 6 months were examined separately for the CTS (n = 31) and tendonitis (n = 36) subgroups. With the CTS subgroup, the right extensor digitorum communis/extensor carpi radialis/lateral epicondyle tendonitis category improved significantly for kb1 (0.91 ± 2.9) and kb3 (0.6 ± 1.5) compared to the placebo (-1.91 ± 3.1) ($P < 0.05$).

TABLE VII. Changes in Physical Examination Measures between Baseline and Sixth Months by Keyboard Group*

	Keyboard group			*P* values[a]
	Placebo	Kb1	Kb3	
Phalen's tests				
Right				0.369
Worse	3 (15)	1 (5)	4 (21)	
Same	12 (60)	15 (79)	9 (47)	
Better	5 (25)	3 (16)	6 (32)	
Left				0.828
Worse	4 (20)	2 (11)	3 (16)	
Same	14 (90)	14 (74)	12 (63)	
Better	2 (10)	3 (16)	4 (21)	
Timed Phalen's test[b]				
Right (seconds)	12.0 ± 20.1 (n = 11)	14.6 ± 27.7 (n = 12)	24.6 ± 14.5 (n = 10)	0.202
Left (seconds)	24.2 ± 26.2 (n = 6)	15.7 ± 22.4 (n = 9)	18.0 ± 17.3 (n = 6)	0.823
Tinel's Sign				
Right				0.502
Worse	4 (20)	5 (26)	2 (11)	
Same	15 (75)	14 (73)	15 (79)	
Better	1 (5)	0 (0)	2 (11)	
Left				0.194
Worse	2 (10)	0 (0)	2 (11)	
Same	18 (90)	14 (73)	15 (79)	
Better	0 (0)	5 (26)	2 (11)	

*Mean ± standard deviations are given for continuous variables. The number of patients (with percent in parentheses) are given for categorical variables. Kb2 was excluded from the analysis due to a low sample size.

[a]*P* value between keyboard groups using Kruskal-Wallis test for continuous outcome variables and χ^2 test for categorical variables.

[b]The duration of time (up to 60 sec) until symptoms of numbness and tingling occur in the areas innervated by the median nerve after wrist flexion. Mean values improved in all keyboard groups. Only participants with a positive Phalen's Test at baseline are included.

Keyboard Preference

Improvement of pain severity was evaluated relative to user's satisfaction with the keyboard as determined at the end of the study. Keyboard satisfaction was correlated with a decrease in overall pain ($r = 0.31$, $P < 0.01$). Satisfaction was trichotomized as: worse than standard (0–3.67) same as standard (3.68–6.74), better than standard (6.75–10). The interaction between satisfaction and keyboard was not significant (two-way ANOVA, $P = 0.54$). A trend toward greater improvement in pain severity was observed with greater satisfaction with the keyboards as displayed in Figure 5 ($P = 0.05$). In general, improvement in pain severity was associated with the group who rated the alternative geometry keyboards as being ''better'' than their usual standard, while worsening of symptom was observed among those who rated their assigned keyboards as being ''worse'' than the standard. The exceptions were (1) 100% of the placebo group who rated their assigned keyboard as being ''better'' or ''same'' as the standard, although their mean pain severity had worsened at 6 months and (2) 35% of kb2 group rated their assigned keyboard as ''worse'' than the standard although their symptom severity had improved over time.

DISCUSSION

This study demonstrates a trend toward greater improvement in overall pain, symptom severity, and functional status in kb3 and to a lesser degree in kb1 users compared to placebo. For kb3, the trend toward lower pain was significant. These findings were consistent with the overall pattern of change in functional status scores. Those assigned to kb3 showed the greatest improvement, followed by kb1 and kb2, while those assigned to the placebo showed worsening pain and discomfort as well as declined functional status. The region of symptom improvement was limited to the forearm regions of the CTS and tendonitis subgroups. There were no significant changes in physical examination findings (e.g., Phalen's test, Tinel's sign, or Finkelstein's test) when the alternative keyboard groups were compared to placebo. Changes in tendonitis severity based on physical examination, however, showed a positive trend toward improvement in kb1 and kb3, with significant severity reduction in the right digital flexors/flexor carpi radialis/medial epicondyle category in the CTS subgroup.

Previous laboratory studies of split geometry keyboards have examined performance, user preference, postural improvement, comfort, or electromyographic activities in healthy subjects following short-term exposure to various experimental conditions [Swanson et al., 1997; Cakir, 1995; Rempel et al., 1995; Gerard et al., 1994; Nakaseko et al., 1985]. The findings of these studies are not consistent and the differences may be related to differences in keyboards evaluated and experimental protocols. In a 2-h laboratory experiment, Gerard et al. [1994] reported decreased electromyographic activities of the finger flexors, extensors, and wrist flexor muscles in typists who typed on the Kinesis™ keyboard in comparison to typing on a conventional computer keyboard. Swanson et al. [1997] reported no significant differences in fatigue, discomfort, and performance between three alternative geometry keyboards used over a 2-day period. In the Swanson study, keyboard E corresponds to kb2 in this study and the configurations of keyboard D, which were based on the settings previously recommended by Kroemer [1972], Nakaseko et al. [1985], and Zipp et al. [1983] were close to the kb3 design, although subjects in her experiment were not permitted to adjust their keyboards. In a study of a split keyboard similar in design to kb1, 26

TABLE VIII. Changes in Tendonitis Severity as Assessed by Clinical Exam Between Baseline and Sixth Months by Keyboard Group*

	Keyboard Group			
	Placebo (n = 20)	**Kb1 (n = 19)**	**Kb3 (n = 19)**	***P* values**[a]
Finkelstein's test				
Right				0.710
Worse	2 (10)	3 (16)	4 (21)	
Same	15 (75)	12 (63)	10 (53)	
Better	3 (15)	4 (21)	5 (26)	
Left				0.961
Worse	2 (10)	1 (5)	2 (10)	
Same	15 (75)	15 (79)	15 (75)	
Better	3 (15)	3 (16)	2 (10)	
EPB/EPL				
Right	0.15 ± 0.9	0.25 ± 0.9	0.33 ± 1.0	0.948
Left	0.25 ± 0.8	0.15 ± 1.4	0.33 ± 0.6	0.949
ECU/FCU				
Right	0.00 ± 1.0	0.40 ± 1.3	0.50 ± 1.6	0.510
Left	0.00 ± 1.3	0.65 ± 1.5	0.22 ± 0.9	0.421
EDC/ECR/LE				
Right	−1.35 ± 4.0	−0.10 ± 3.5	0.44 ± 1.3	0.208
Left	−0.40 ± 2.7	0.15 ± 3.8	0.72 ± 1.5	0.420
FCR/DF/ME				
Right	0.15 ± 1.8	0.75 ± 2.3	0.39 ± 1.2	0.115
Left	−0.40 ± 2.8	1.10 ± 2.9	1.10 ± 1.4	0.765
No. sites with reduced severity[b]				
Right (sites per subject)	1.19 ± 1.7	2.83 ± 2.7[c]	2.59 ± 1.6[c]	0.030
Left (sites per subject)	1.61 ± 2.0	2.61 ± 2.3	1.78 ± 1.6	0.278

*Mean ± standard deviations are given. Negative values indicate worsening of symptom over time. If more than one tendon site is included in the category, the average values across tendon sites are reported. EPL = extensor pollicus longus, EPB = extensor pollicis brevis, ECU = extensor carpi ulnaris, FCU = flexor carpi ulnaris, EDC = extensor digitorum communis, ECR = extensor carpi radialis, LE = lateral epicondyle, FCR = flexor carpi ulnaris, ME = medial epicondyle, DF = digital flexors. Kb2 was excluded from the analysis due to a low sample size.

[a]Statistical significance between keyboard groups using Kruskal-Wallis test ($P < 0.10$).

[b]Number of tendonitis sites which showed improvement in severity over 6 months period (e.g., change from severe pain at baseline to moderate/mild pain at 6 months or change from moderate/mild pain at baseline to no pain at 6 months).

[c]Mean significantly different from placebo using a one-tailed Dunnett's test ($P < 0.05$).

experienced typists reported subjective ratings after 4 h of typing to be equal as or more favorable than the conventional keyboard for its design, posture, and general comfort [Cakir, 1995]. Rempel et al. [1995] reported a significant wrist and forearm postural improvement toward neutral among 50 experienced typists who typed for 10 min on a fixed split keyboard similar in geometry to kb3. Nonetheless, after this brief exposure, subjects preferred the conventional keyboard over the alternative geometry design for its key feel and touch, performance, ease of use, and postural requirements. Yet, in an earlier study, Nakaseko et al. [1985] reported that subjects felt significantly ''less tense'' when using a fixed split keyboard with a design similar to kb3 after 30 min of typing and greater than two-thirds of the subjects preferred the experimental keyboard over the traditional flat keyboard. Inconsistent preference findings may stem from the fact that the exposure duration commonly utilized in the laboratory are short, typically lasting from 10 min to 2 days, therefore, subjects may be responding to other features (e.g., the newness, design novelty, unconscious cues from researchers, etc.). With these brief exposures, typists are unlikely to have adapted their engrained motor patterns to the new designs. Or, they may experience temporary discomfort based on use of new muscle groups. Moreover, these are controlled experimental conditions, which will differ from the ''real'' workplace setting.

In our study, overall pain severity decreased initially (week 6) in all keyboard groups, including the placebo group. Such an early decrease in pain suggests a possible ''placebo effect.'' Indeed, in the conventional/placebo group,

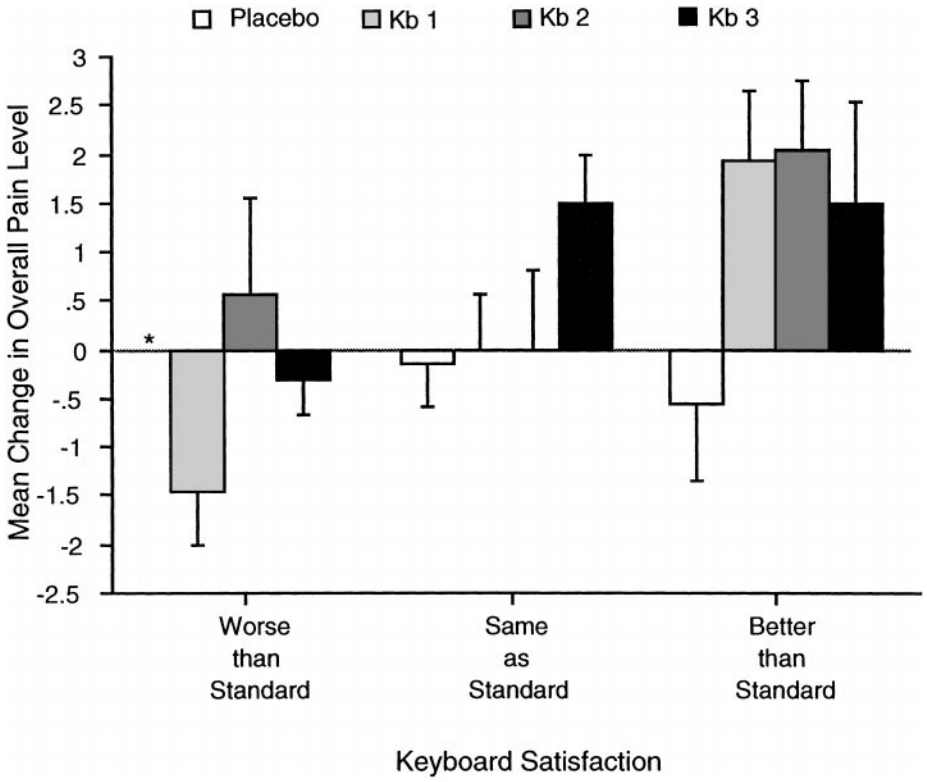

FIGURE 5. Mean change in overall pain level (positive is improvement) over 6 months as a function of keyboard satisfaction [rated as worse than standard (0–3.66), same as standard (3.67–6.74), better than standard (6.75–10)] and keyboard groups. In general, those reporting a reduction in pain also reported higher keyboard satisfaction (two-way ANOVA, $P = 0.05$). *None of those assigned the placebo reported it ''worse than standard.''

this effect disappeared in week 12 and later. Only in kb3, did the initial reduction in pain persist. In another longitudinal intervention study involving two computer keyboards, the change in pain and discomfort level between the two keyboard groups was not significantly different until 12 weeks [Rempel et al., 1999]. Hence, subjective measures of user preference and comfort ratings reported in short-term studies may be misinterpreted as they are likely to be influenced by the ''placebo effect'' [Skov and Kristensen, 1996] or resistance to a new design and probably do not predict long-term health effects. It is likely that exposure periods of 12 weeks or more are needed to detect persistent health effects associated with alternative keyboards. Short-term laboratory studies, however, can be beneficial in evaluating muscle load, postural patterns, or other physiological effects that are unlikely to change even after prolonged use [Honan et al., 1996].

Although the pain severity measure showed a trend toward greater improvement in kb3, 35% of this group reported no change in their pain level at 6 months of keyboard use, suggesting that the potential benefits derived from this keyboard may not be the same for all individuals. Improvement may be influenced by other workplace factors such as the subjects' workstation design, job tasks, and work behavior.

This study has several potential limitations. First, the physical examinations were focused on both nerve- and tendon-related findings. These measures are less sensitive outcome measures than symptom or hand function ratings [Levine et al., 1993]. The small sample size of 20 per group may not yield the statistical power needed for the detection of effects in clinical outcome measures, especially within the even smaller CTS and tendonitis subgroups. If improvements occur in multiple body sites, larger sample sizes or longer study durations will be needed to detect an effect in specific physical examination maneuvers.

Second, the high dropout rate (45%) in kb2 may result in an underestimation of the true intervention effect due to ''survivor bias'' (early loss of subjects due to symptom worsening). Survivor bias was minimized by carrying forward the last available value in the analyses of pain and function outcome. Excluding this keyboard group entirely from the analyses of the clinical outcomes was necessary because follow-up physical examination measurements were not made in 45% of this group. Therefore, no conclusions on

the relationship between kb2 use and symptom changes can be drawn.

Third, cost and invasiveness of the nerve conduction velocity studies did not permit us to include this test as part of the diagnostic criteria. At this time, there is no universally accepted diagnostic ''gold standard'' for musculoskeletal disorders. Electrodiagnostic studies are objective tests for CTS, although the false-negative rate for nerve conduction results ranges from 5–27% [Rempel et al., 1992]. Bernard et al. [1993] found that among office workers (e.g., reporters, editors), a case definition based on hand symptoms and positive physical findings was associated with abnormal median nerve conduction. Our case definition and physical examination maneuvers were similar to those used by Bernard et al. and other investigators [Bergqvist et al., 1995; Hales et al., 1992; Baron et al., 1990; Burt et al., 1990].

A major strength of this study was the relatively successful random allocation of subjects to evenly distribute potential covariates between keyboard groups. For the clinical measures, observer bias was minimized by blinding the examiners to subject's previous medical history and keyboard assignments during the baseline and final examination. In addition, placebo controls were used to equalize potential psychological effects associated with receiving a new treatment among randomized groups [Pocock, 1991]. In fact, a ''placebo effect'' was observed when subjects rated the placebo as different from standard (Fig. 5). Finally, our study is one of only two randomized intervention trials of musculoskeletal disorders among computer users to date. The longitudinal design permits an evaluation of important changes in clinical, health, and functional measures over long-term keyboard use in a real office environment.

In summary, our findings suggest that computer users with hand pain may experience a reduction in pain and improvement in function if they use kb3. However, this is the first long-term intervention trial to evaluate split geometry keyboards. These initial findings should be replicated in other clinical intervention trials.

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