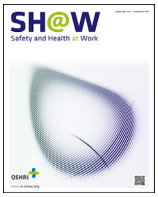
Safety and Health at Work 7 (2016) 347–353

Contents lists available at ScienceDirect

Safety and Health at Work

journal homepage: www.e-shaw.org



Original Article

Key Strike Forces and Their Relation to High Level of Musculoskeletal Symptoms

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ARTICLE INFO

Article history:
Received 28 July 2015
Received in revised form
11 March 2016
Accepted 28 April 2016
Available online 14 May 2016

Keywords:
ergonomics
key strike force
work-related musculoskeletal symptoms

ABSTRACT

Background: This study aimed to investigate the relation between key strike forces and musculoskeletal symptoms (MSS). Moreover, this study presents a key strike force measurement method to be used in a workplace setting. The correlation between key strike force characteristics and MSS was previously studied, but the measurement methods used either a single-key switch or force platforms applied under the keyboard. Most of the studies were conducted in a laboratory setting. The uniqueness of measurement methods in the current study is their ability to measure forces applied to a specific key in a workplace setting and to provide more information about specific key strike forces during typing.
Methods: Twenty-four healthy computer workers were recruited for the study. The demographic questionnaire, and self-reported questionnaires for psychosocial status (General Nordic Questionnaire for Psychological and Social Factors at Work) and for detecting MSS were filled up, which later helped in dividing the participants into two groups (12 participants with pain and 12 without pain). Participants typed a predetermined text that utilized the instrumented keys multiple times. The dynamic forces applied to the keys were recorded and collected, using four thin and flexible force sensors attached to the preselected keys according to their location.
Results: The results demonstrated that participants with high levels of MSS, specifically in the back and neck, in the last year exerted significantly higher key strike forces than those with lower levels of symptoms ($p < 0.005$).
Conclusion: The key strike force exerted while typing on a keyboard may be a risk factor for MSS, and should therefore be considered in ergonomic evaluations and interventional programs.

1. Introduction

Typing is considered a risk factor for musculoskeletal symptoms (MSS) of the upper extremities (UEs), neck, and lower back [1–4] Approximately 50% of workers who use computers daily complain of MSS [1,5].

Several risk factors in the working environment have been identified, including repetitive work; awkward postures of the trunk, neck, and UEs; and improper adjustment of the seat, keyboard, and monitor [6,7]. Among the studies on the myriad risk factors, those on key strike forces and their correlation with MSS are relatively limited. Only a few researchers have studied the correlation between measurements of key strike forces and MSS. Several studies about key strike forces used a single-key switch specially designed for the study [8], while others used force platforms that did not relate to specific fingers and MSS [9–14]. Feuerstein et al [12] found in their case–control study that individuals with high levels of UE symptoms exerted significantly higher key strike forces than those with lower levels of UE symptoms (3.5 N and 2.75 N, respectively). Pascarelli and Kella [15] videotaped computer workers and found that “clackers,” i.e., vigorous key strikers, suffered from UE MSS. Hughes et al [16] measured the effect of mental workload and time pressure on perceived workload and physiological responses, and concluded that limiting the time for task completion increased muscle activity, mental load, and key strike forces.

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http://dx.doi.org/10.1016/j.shaw.2016.04.008

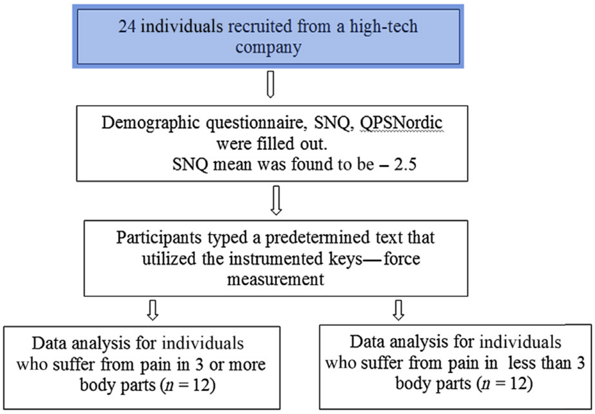

Fig. 1. Flow chart of trial protocol and participant allocation. QPSNordic, General Nordic Questionnaire for Psychological and Social Factors at Work; SNQ, Standardized Nordic Questionnaire.

Other researchers studied the relationship of key switch characteristics and keyboard design with discomfort and pain [13,17–19]. Asundi and Odell [10] recently reviewed literatures related to key strike forces, and summarized that when a higher force is required to activate the key, then greater key strike force and Electromyography (EMG) activity are generated. It was found that computer users strike the keys with a force two to seven times higher than that required to activate the key. Literature reviews present different measuring methods and different locations (i.e., workplace vs. laboratory settings). The literature is inconclusive concerning the best method to measure key strike forces and their correlation with MSS. The current study aims to present a practical measurement of key strike forces in a workstation environment and intensify the investigation regarding the force applied to the keyboard and its correlation with MSS.

Our hypothesis suggested that individuals with high levels of MSS exerted significantly higher key strike forces than those with lower levels of symptoms.

An understanding of the relation between force and MSS may lead to establishing better guidelines for evaluation and interventions, taking into account the key strike forces applied during typing.

2. Materials and methods

2.1. Participants

The current study was a case–control study with one control per experimental individual (Fig. 1). The inclusion criteria were as follows: healthy with or without MSS measured by the Standardized Nordic Questionnaire (SNQ) and right-handed computer workers who spend more than 4 hours a day typing on a computer keyboard in a high-tech company. The exclusion criteria were previous or current orthopedic injuries, neurological deficits, or any medical conditions associated with swelling of the joints or hand numbness, e.g., pregnancy, diabetes, heart condition, or arthritis. Sample size was calculated based on the results of a previous key strike reliability study in which the response within each group was normally distributed with a standard deviation of 0.11. If the true difference between the experimental and control means is 0.15, we will need to study at least 10 experimental individuals and 10 control individuals to be able to reject the null hypothesis that the population means of the experimental and control groups are equal, with a probability (power) of 0.8. Type I error probability associated with the test of this null hypothesis is 0.05. Twenty-four computer programmers volunteered, and were recruited from one high-tech company who signed a consent form (19 females and 5 males; mean age and standard deviation of 31.9 ± 4.9 years) (Table 1). All the participants were working in a similar environment, i.e., using similar tables and chairs, under similar temperature condition controlled by air conditioning, and having similar work tasks. Other biodemographic and work characteristics are described in Table 1. The participants were divided into two groups according to the number of painful body parts reported in the SNQ. Since 2.5 was the mean number of painful body parts in the last year, the one group had those with less than three painful body parts in the last year and the other those with more than three painful body parts in the last year.

Table 1
Descriptive data of the demographic and job characteristics, anthropometric data psychosocial status of the participants ($N = 24$)

	Minimum	Maximum	Mean	SD
Demographic and job characteristics				
Age (y)	25	46	31.9	4.9
Education (y)	12	18	15.7	1.4
Years in work place	0.3	9	3	2.6
Work hours per day	9	12	7.5	1.4
Computer work per day (h)	4	9	7.6	1.3
Percentage using keyboard	20	100	69.8	20.3
Number of breaks per day	1	8	3.9	1.9
Length of breaks (min)	5	45	14.3	11.2
Psychosocial status of participants				
Control of decision	2.73	4.55	3.72	0.45
Predictability at work	3.00	5.00	4.07	0.40
Social interaction	3.38	5.00	4.09	0.49
Fair leadership	1.25	5.00	3.40	0.75
Organizational climate	1.60	4.50	3.40	0.56
Interaction with private life	1.00	5.00	2.90	1.11
Organizational commitment	1.00	5.00	3.41	0.94
Anthropometric data				
Height (cm)	162	185	175.1	6.4
Weight (kg)	49	92	74.5	11.5
Length of arm (cm)	28	36	32.2	2.33
Length of forearm (cm)	23.5	29	26.2	1.42
Length of hand (cm)	15.5	19.5	17. 9	0.98

2.2. Instrumentation and outcome measures

Force sensors (FlexiForce Model A201; Tekscan Co., South Boston, MA, USA) were used to measure striking forces exerted by fingertips while typing on a designated keyboard ("anti-Repetitive Strain Injury (RSI)") (Fig. 2). These sensors had been tested previously and were found to be reliable [20,21]. The piezoresistive force sensors are extremely flexible and thin (with a thickness of 0.2 mm). The force range is 0–1 pound (0–4.4 N). Linearity is (error) < ±3% and repeatability is ±2.5% of the full scale. The active sensing area is located on the edge of the sensor, marked as a circle with a diameter of 9.53 mm, while the width of a single key in the selected keyboard is 15 mm. Since the contact between the key and the fingertip during the typing task may not fall directly on the active sensing area of the sensor, the current study presents a measurement method in which a washer with a diameter of 5 mm was glued to the center of each sensor (Fig. 2). This layout ensures that the entire force applied by the user was transferred to the sensor.

Six common keys used in typing were preselected for the study, with two keys in each row—one on the right side and another on the left side. Four sensors were active (on the keys "R," "C," "comma," and "U"), and two were dummy sensors (on the keys "A" and "T"); the participants were not aware of which sensors were active. Force data

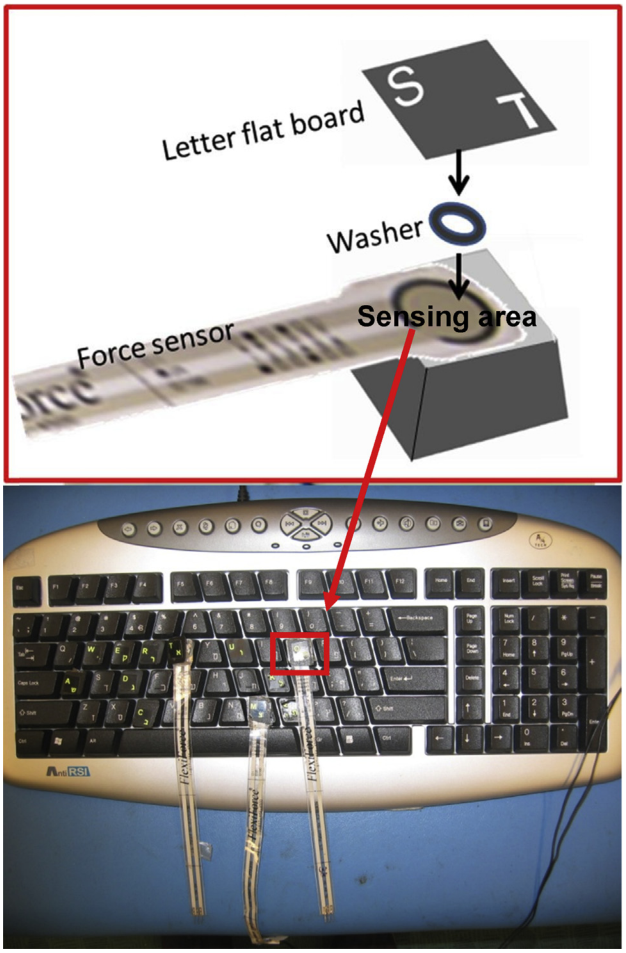

Fig. 2. Force measurement setup. A washer, 5 mm in diameter, glued to the center of each of the four force sensors, was attached to the key. A flat board had the corresponding letter printed on its upper side.

were sampled at 1 kHz. Every sentence that was typed resulted in at least four key strikes on each force-measuring sensor. The data were recorded using LabView 8 software (National Instruments Co., Austin, TX, USA). Each sensor was calibrated according to the manufacturer's instructions, as gradual force was applied to each sensor via an Instron 5544 testing machine in order to fit the applied force to the resultant voltage measurement. A pretrial recording, in which no force was applied to the sensors, showed maximal system noise of 0.04 V, which corresponds to a force of 0.07 N. Readings below this threshold value were nullified. Aside from the calibration trials for the sensors, the data were not filtered so as not to affect the maximal value, similar to the performance with the same hardware in the impact study by Ouckama and Pearsall [21]. The peak force exerted on each trial, the mean peak force of four repetitions in the same sentence, and the total mean peak force were calculated for all four force sensors across key strokes and trials.

A test–retest pilot study ($n = 14$), with a 1-week interval between the first and the second test, was conducted separately before the actual study began, in order to assess the reliability of this measurement method. The peak force exerted on each key and the total mean peak force on all four force sensors were recorded and analyzed. The peak force of 15 repetitions was collected from the "M" key. The interclass correlation for the mean force, standard deviation, and peak force were moderate to high ($0.68 <$ interclass correlation < 0.81). The interclass correlation for the peak forces were 0.68 for a single measure ($0.255 <$ 95% confidence interval < 0.88; $p = 0.003$) and 0.81 for the mean measure ($0.41 <$ 95% confidence interval < 0.81; $p = 0.003$). The force sensor was found to have acceptable test–retest reliability.

The SNQ was used to register the presence and anatomical location of the MSS, as well as the severity of symptoms, as reported by the participants [22]. The SNQ was found valid and reliable in evaluating MSS [23]. The MSS score was calculated by counting the number of painful body areas reported during the preceding week and the preceding year (each of the following body areas got 1 point—neck, 2 shoulders, 2 elbows, 2 wrists, upper back, lower back, 1 or 2 hips, 1 or 2 knees, and 1 or 2 legs and ankles—for a maximum of 13 points). Severity of pain was calculated for each body part separately (between 0 and 14 points for the neck and low back, and between 0 and 19 points for the shoulders and UEs). An appendix for UEs (arms, forearms, wrists, and fingers) was recently added to the SNQ and validated [24]. In addition, the percentage of participants who have experienced MSS during the past year and in the past week was calculated, providing a literal description of the MSS. The percentage of participants who experienced pain in the shoulder, neck, back, and UEs was calculated as well (Fig. 3).

A biodemographic questionnaire collected anthropometric data of the arm, forearm, and hand length of each participant, along with health status and characteristics of computer work habits (Table 1).

The General Nordic Questionnaire for Psychological and Social Factors at Work (QPSNordic) [25] was used for studying the psychosocial status.

2.3. Trial protocol

The Human Subjects Committee of the institution, where one of the authors (N.R.) is employed, gave approval for this study. Each participant provided signed consent.

The biodemographic questionnaire, SNQ, and QPSNordic were completed prior to testing. Anthropometric measurements were then collected (Table 1). The study was conducted at a standard workstation located in a high-tech company. The tables and chairs of the study station were provided by the company, and are identical to those used by all the participants in their daily stations. The participants were instructed to sit, adjust the station to a comfortable position, and commence typing a predetermined sentence on the instrumented keyboard. An identical typing task

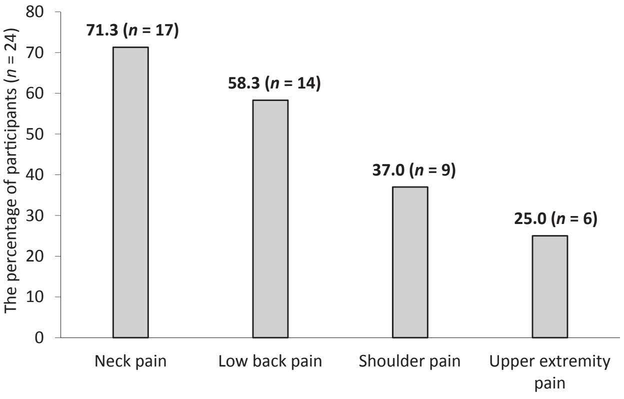

Fig. 3. Distribution of pain locations among all participants who experienced pain in the last year. The duration of pain in both the preceding week and the preceding year was calculated. The symbol 'o' presents values that are 1.5–3 box length from the edges of box.

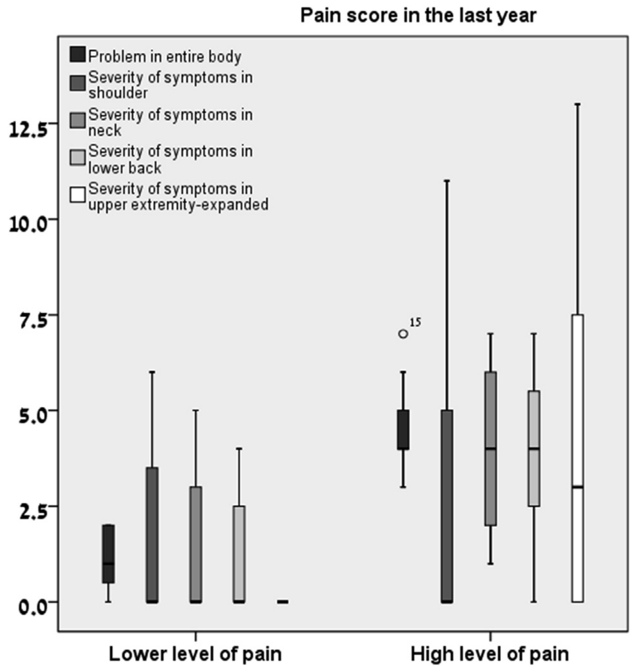

Fig. 4. Pain severity. Mean and interquartile range of pain in each group: pain in the entire body in the last year (scale of 0–13), and severity of pain in the neck and low back (scale of 0–14) and in the shoulders and UEs (scale of 0–19) (left and right). Scores refer to the effect pain had on the performance of work activities and the quality of leisure time. The score calculates the duration of pain both during the preceding week and during the preceding year. The symbol 'o' presents values that are 1.5–3 box length from the edges of box. UE, upper extremity.

was repeated three times, resulting in at least 12 key strikes on each force sensor.

2.4. Data analysis

The participants were divided into two groups according to the number of painful body parts reported in the SNQ. The peak key strike was identified as a maximal force when the force suppressed the noise threshold for at least 5 milliseconds. The Word files typed by each participant during the trials were saved so that the number of actual key strikes were counted and compared with the number of key strikes identified in the force data, to ensure that the latter did not exceed the former. Repeated-measure analysis of variance was conducted in order to compare peak key strike repetitions for each participant on the same key.

The Kolmogorov–Smirnov test was conducted to evaluate the distribution of the primary outcomes (force and pain). Normal distribution was found for the key strike forces and other biodemographic variables. The psychosocial status was described in ordinal scales, and therefore the Mann–Whitney test for nonparametric variables was used to test the differences between the psychosocial statuses of the two groups.

Descriptive statistics were conducted. The mean peak key strike force for each key and the total mean key strike forces of all the keys were calculated. The interquartile range of SNQ scores was described graphically, and the percentage of participants who experienced pain in each body part was measured as well. A *t* test was used to compare the two groups by means of parameters such as working hours a day, working hours in front of the computer, and anthropometric data, and the Mann–Whitney test was used for the psychosocial status. The *t* test analysis was used for comparing between the key strike forces of the groups, to detect whether those who suffered from MSS in the last year and those who suffered from a high level of pain in the back and neck exerted higher key strike forces than those who did not suffer. The number of those suffering pain in the UEs and the shoulders was very small, and therefore could not be obtained statistically.

The statistical analyses were performed with SPSS version 17. An alpha level of 0.05 was considered significant.

3. Results

Descriptive statistics of the biodemographic variables are presented in Table 1. No differences in age, hours of working on the computer, anthropometric data, psychosocial status, and typing style were found between the two groups.

The SNQ questionnaire showed that 87.5% ($n = 21$) of the participants suffered from pain in at least one body part in the year preceding the trial. The distribution of pain according to body parts is presented in Fig. 3. The percentage of participants who experienced MSS during the week prior to the study was 58.3% ($n = 14$). Descriptive statistics (e.g., mean and interquartile ranges of the severity scores) are described in Fig. 4.

The hypothesis suggesting that individuals with high levels of MSS exerted significantly higher key strike forces than those with lower levels of symptoms was confirmed. Significant differences in key strike forces were found between those who suffered from MSS in the last year, those with high severity of pain in the neck and back, than those who suffer from lower-level symptoms (Tables 2 and 3).

Results regarding mean striking forces for each group are detailed in Tables 2 and 3. The mean force measured for all the participants was 1.25 N (for the letter "R"), followed by 0.81 N for the letter "U", 0.80 N for the "comma" key, and 0.76 N for the total key force. No significant differences were found within each participant's strike force repetitions on the same key (repeated measures analysis of variance test; $F = 1.55$, $p = 0.1$); however, significant differences were found between the mean striking force applied on the four keys (repeated measures test; $F = 21.53$, $p = 0.00$). *Post hoc* analysis using the Bonferroni method revealed

Table 2

Independent *t* test to compare between the key strike forces exerted by those who suffer from higher-severity back pain and those who suffer from lower-severity back pain

Measured force (N)	Mean force Low-severity MSS	SD	Mean force High-severity MSS	SD	Independent t test severity of back pain	
					t_{22}	p
For the letter "U"	0.37	0.16	0.56	0.17	−1.94	0.07
For the letter "C"	0.25	0.19	0.39	0.18	−2.35	0.02
For the sign "comma"	0.36	0.18	0.47	0.13	−3.40	0.03
For the letter "R"	0.64	0.23	0.88	0.18	−0.81	0.42
Total mean force	0.40	0.11	0.59	0.13	−2.63	0.01

MSS, musculoskeletal symptoms; SD, standard deviation.

Table 3
Independent *t* test to compare between the key strike forces exerted by those who suffer from higher-severity neck pain and those who suffer from lower-severity neck pain

Measured force (N)	Mean force Low-level MSS	SD	Mean force High-level MSS	SD	Independent *t* test severity of neck pain	
					t_{22}	*p*
For the letter “U”	0.39	0.17	0.54	0.10	−1.94	0.07
For the letter “C”	0.23	0.17	0.41	0.19	−2.35	0.02
For the sign “comma”	0.32	0.12	0.52	0.14	−3.40	0.03
For the letter “R”	0.72	0.23	0.79	0.18	−0.81	0.42
Total mean force	0.42	0.13	0.56	0.13	−2.63	0.01

MSS, musculoskeletal symptoms; SD, standard deviation.

significant differences between the striking forces, as measured by the sensors attached to the key “R” and all the other letters ($p = 0.00$).

4. Discussion

In the present study, key strike forces were measured in a workstation environment with thin force sensors attached under specific keys, measuring the force exerted during typing. This study aimed to investigate key strike forces and their relation with MSS. Significant differences in key strike forces were found between those who suffer from lower level of symptoms and those who suffered from a high level of MSS, specifically high-severity pain in the back or neck, in the last year. Feuerstein et al [12] found similar results regarding pain and symptoms even though the measurement methods and the range of force measured were different. They recorded the reaction forces exerted during typing on two strain-gauge force transducers applied to the keyboard, and found that individuals with a high level of symptoms exerted significantly higher key strike forces than those with a lower level of symptoms (3.5 N and 2.75 N, respectively). In addition to the differences in the measurement method, the typing task and its timing were different. Participants in the studies of Feuerstein et al [12] and Armstrong et al [9] were asked to perform a 15-minute typing task during weekend, while in the current study the typing task was shorter and was performed during working hours. Pascarelli and Kella [15] videotaped 53 computer workers and found that “clackers,” i.e., vigorous key strikers, suffered from UE symptoms. The low range of force might be explained by two factors: the use of an anti-RSI keyboard, which was activated by a light touch, and the measurement method, which will be discussed later. Pascarelli and Quilter [26] support these results while discussing the fact that every individual has an specific typing style and that even the best ergonomic keyboard cannot circumvent the pain caused by a harmful typing technique. Regarding force measurements, in the present study, the total mean key strike forces ranged from 0.40 N to 0.76 N, which is lower than the range of forces reported in the literature [8,9,27]. The differences are possibly because of a great variety in the measurement methods and the typing task, as mentioned earlier. Some researchers used the method where load cells were fixed under the keyboard [9,14]. Others built a single experimental apparatus in the laboratory [17], or used a single-key strike apparatus and measured the force exerted by a single finger [8,9,27]. The differences could be attributed also to the choice of sensors (FlexiForce vs. strain gauge), study environment (laboratory vs. workplace), or keyboard design and other characteristics, e.g., activation force and key travel, which are known to affect the applied force [10], as discussed in the Introduction.

The current study results were surprising; it was expected to find a relation between neck and UE pain symptoms and key strike forces, but the results pointed to specific symptoms in the neck and back and their relation to exerting high strike forces. These results could be explained by the biomechanical theory that describes the body as a related system with several segments. Muscles of these segments usually work synergistically, from the proximal part to the distal part, in order to perform a specific task. Associations between proximal posture of the trunk, neck, shoulders, and other muscles located distally were established, likely to enable adequate task performance [28–30]. Moreover, voluntary rapid arm movements are generally accompanied by proximal stabilization, although constant postural changes and adjustments are made in order to maintain this stability. The amplitude and timing of these adjustments increase whenever there are more postural changes and low levels of stability [31]. The ergonomic literature concerning typing and rapid finger movement, while being aware of body biomechanics, advised that continuous typing should normally be performed while sitting and that the trunk should be stable and relaxed, whereas unsupported sitting will need a greater active proximal stabilization of the neck, shoulders, and back [32,33]. Furthermore, several intervention programs focused specifically on the shoulders and neck, in order to prevent MSS in those body areas. Among these is the exercise program for reduction of work-related MSS in the upper limb, established by Rasotto et al [34,35]. The latest research found that a tailored physical activity program was significantly effective in reducing shoulder and neck pain symptoms. A tailored physical activity similar to a tailored ergonomic work station adjustment should be considered as a prevention program for typists or other workers at risk.

Additional analysis concerning the rate of MSS showed a high rate of pain in the back and neck; these results are not surprising. It was found that 58% of the participants suffered from MSS in the week preceding the study, which is in accordance with the published literature on computer workers of high-tech companies performing under the same working conditions (working more than 4 hours per day) [5]. Some studies indicate a higher prevalence of neck and back symptoms than arm–hand problems [32,36]. There are also other studies that report a higher prevalence of arm–hand problems [37].

Significant differences were found between the mean peak strike forces exerted on different keys. The mean force exerted on the “R” and “U” sensors was higher than the striking force measured by the “C” and “comma” sensors (see Tables 2 and 3). This was probably a result of the key location, as “R” and “U” are in the distal key line, while “C” and “comma” are located proximally. The difference in striking forces on different keys in the keyboard was previously documented. Woods and Babski-Reeves [38] found differences between the force exerted on different keys (“N,” 1.07 N vs. “E,” 1.02 N) and explained that this might be due to the location of the key. The current results strengthen the results of Woods and Babski-Reeves [38] and demonstrate the need for separate sensors for different keys, which can explain pain in different fingers in the future.

Several limitations of this study should be noted. The small sample size and the fact that all participants had the same work task limit the ability to generalize the study results to other computer professions (e.g., typists and Video Display Terminals (VDT) operators). Moreover, differences in working schedule and the number of breaks may also affect the results technically. Since we measured the forces exerted only on a few keys, further studies should be conducted to measure the strike forces exerted on other keys or on all keys, to find out the effect of key location on the force exerted. Finally, since the participants typed freely, we could not determine which fingers were used for key activation, and thus, we could not distinguish between forces exerted by different fingers. In future, this study should be repeated with more sensors applied under the keys and the participants should know to type blindly, in order to assess the force exerted by a particular finger. We can only assume that using different fingers affected the results, increasing the variability between the participants.

The results demonstrated that individuals with high levels of MSS in the last year, specifically those with symptoms in the back and neck, exerted significantly higher key strike forces than those with lower levels of symptoms. The results emphasized the need to consider excessive fingertip striking forces as a relevant risk factor while assessing MSS associated with typing. The use of thin FlexiForce sensors provided a practical method for measuring the strike forces exerted by each fingertip while performing a typing task in the workplace setting. Based on these results, key strike forces, exerted by different fingers, on each key can be measured. Further investigation should be planned in order to investigate key strike forces exerted during working, or in different tasks and variety of computer workers.

Conflicts of interest

We state that there is no conflict of interests.

Acknowledgments

The authors thank Gal Mayer, Mayan Yankelevitz, Ifah Arbel, and Oshrat Feldman, students of occupational therapy, for their help in collecting the data for this research.

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