THEORECTICAL & EXPERIMENTAL STUDIES

Observations on the Relationship Between Key Strike Force and Typing Speed

AUTHORS
Carolyn M. Sommerich[a]
William S. Marras[b]
Mohamad Parnianpour[b]

[a]Department of Industrial Engineering, North Carolina State University, Box 7906, Raleigh, NC 27695;
[b]Department of Industrial, Welding, and Systems Engineering, The Ohio State University, 1971 Neil Ave., Columbus, OH 43210

This article explores the relationship between repetition/typing speed and force in keyboarding. Based on analysis of data collected on the job from professional keyboard operators and experimental laboratory data, the following observations are presented: (1) Individuals typing at preferred speeds tend not to exhibit a relationship between typing speed and average peak force; (2) across individuals typing at preferred speeds, there is no relationship between typing speed and force; (3) when an individual's typing speed is affected by external influences, typing force tends to increase or decrease with similar changes in typing speed.

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For some time now high repetition, high force, awkward postures, and lack of rest have been recognized as risk factors for work-related upper extremity disorders such as tenosynovitis, carpal tunnel syndrome, tendinitis, and DeQuervain's disease.[1-5] The first two factors, as they relate to the task of typing, are the focus of this article.

It would be difficult to dispute the assertion that typing is a highly repetitive task, based on the definitions of high repetition appearing in the literature on work-related upper extremity disorders. Some keyboard operators may type in excess of 10,000 keystrokes per hour (about 168 key strokes per minute).[6,7] This level of repetition far exceeds rates of other kinds of previously identified highly repetitive, hand-intensive, manual tasks. Silverstein et al.[5] rated manufacturing tasks as highly repetitive if they were performed more than twice per minute. Hammer[8] was of the opinion that human tendons could not tolerate more than 1500–2000 manipulations per hour (equivalent to 25–33 per min). Marras and Schoenmarklin[9] performed a study that was limited to highly repetitive, hand-intensive manufacturing tasks, wherein the average number of fundamental wrist movements was approximately 25,000 per shift (55 per min.).

It is more difficult to support the case that typing involves high force, when average peak key strike forces from touch typists studied in laboratory settings are reported to be, on average, only 2–3 N.[10,11] Manual jobs that Silverstein et al.[5] categorized as low force had average hand force requirements of 29 N (±16), while high force jobs required 125 N (±84). However, Silverstein et al.[5] found the interaction of force and repetition to be more important than either factor alone. This may be a critical issue in typing, as well. Rather than focusing exclusively on peak key strike force, the accumulation of repeated force may also be an important factor in trying to understand the relationship between keyboard activities and upper extremity disorders and symptoms.

Rempel and Gerson[10] suggested that cumulative force exposure may contribute to development of chronic musculoskeletal disorders. Other researchers have also identified the need for integrated measures that meaningfully combine two or more external measures.[12] Yet estimates of cumulative force rarely appear in the scientific literature.[12,13] Cumulative typing force is a function of total typing time, as well as a number of varying factors, including typing speed (repetition), force exerted during individual key strikes, and duration of individual key strikes. An estimate of 25–27 tons per day (approximately 11 kN/day) of total typing force, from an unreferenced Stanford University study, appeared in a computer trade journal.[14] However, such simplified estimates, based only on average peak key strike force, average typing speed, and an assumption of 7 or 8 hours

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of continuous typing, do not correctly characterize cumulative force exposure. Recently, Sommerich et al.[13] estimated cumulative force for four data entry operators based on employer records of daily keying activity and samples of key strike force measurements, where force was recorded during several hundred key strikes. Cumulative force estimates for the four subjects ranged from 3.7–14.4 kN•sec/day.

In addition to cumulative force, there may be another way in which force and repetition interact during a typing task. Armstrong et al.[11] observed an inverse relationship between force and typing speed. However, in their study of professional keyboard operators in a laboratory setting, Feuerstein et al.[15] found no relationship between typing speed and key strike force. There may be some benefit in determining under what circumstances an association between force and typing speed exists. This article presents an examination of the interaction of typing speed and typing force, including peak key strike force and cumulative force. This is accomplished through the exploration of two sets of typing data—one based on observation of professional typists in the workplace, the other based on an experimental laboratory protocol.[13,16]

METHODS

Apparatus

Key strike force was measured with a pair of small force plates, ⅝ in. thick (1.6 cm), on which a subject's keyboard was placed. A matched pair of piezo-resistive miniature force transducers detected the forces exerted on the force plates through the keyboard (Model 9211, Kistler Instrument Corporation, Amherst, N.Y.). Vertical forces were summed from the two transducers. Data were sampled at 600 Hz in 6-sec intervals. Data were later filtered and analyzed to produce statistics of average peak force, 95th percentile force, and cumulative force.

Data Set 1. Key Strike Force and Typing Speed On-the-Job: Assessment of Professional Keyboard Operators

A number of quantitative biomechanical measurements including key strike force were collected from 25 professional keyboard operators. This data set provided the material for addressing questions of relationships between force and typing speed, both within and across individuals typing at preferred speeds. The subjects and data set are only briefly described here. A detailed description can be found in Sommerich et al.[13] In their employment, subjects performed either traditional data entry (8 subjects), word processing (7 subjects), or interactive data entry work (10 subjects). Traditional data entry was primarily a right-hand operation, compared with a more balanced use of hands in word processing. Interactive entry was a mix of one- and two-handed typing. Subjects volunteered for the study; gave written informed consent, and participated on company time. All subjects were pain-free at the time of testing, though some had previously experienced some degree of upper extremity discomfort. Subjects ranged in age from 22 to 55 years (mean=34 yrs, SD=9). Typing experience ranged from 1 to 25 years (mean=11 years, SD=7). History of formal typing training was not gathered from the subjects. Data from 24 of the 25 subjects are presented in this article, due to difficulties in assessing typing speed for one interactive entry operator.

The study was observational in design. Subjects worked at their own workstations, using their usual computer or terminal. Data were collected from each subject during one 60–90 min time period, during which subjects were asked to perform their normal typing tasks. Prior to data collection, subjects were given 10 min to acclimate to the apparatus and to make adjustments in seat height if they desired. Subjects were not told that key strike force was being measured. They were only told that the plates under the keyboard helped identify key strike timing. They were also specifically told that typing speed was not being judged, and that they were to type as they normally did, no faster, no slower. Fifteen to 25 data samples of 6 sec each were collected for each subject. Subjects were unaware of precisely when the samples were collected. Following data collection, several crude key activation force samples were collected prior to removal of the force plate from the worker's area. These measurements involved recording the force exerted by the researcher in activating a few alpha and numeric keys with the lightest touch possible. Key travel was not measured.

Data Set 2. Key Strike Force and Typing Speed in a Controlled Setting: External Influences on Typing Speed

A number of quantitative biomechanical measurements, including key strike force, were collected from five volunteer female touch typists in a laboratory setting. The purpose of the study was to examine the effects of three different changes in typing condition on typing biomechanics. This data set provided material for addressing questions about the relationship between force and typing speed when typing speed varied due to external influences; in other words, when subjects typed at other-than-preferred speeds. Some changes in typing condition elicited alterations in typing speed. The associations between those typing speed alterations and changes in typing force are examined in this article.

All laboratory subjects typed the same text material on the same Apple Adjustable Keyboard. This keyboard can be used in a closed (standard keyboard orientation) or in several split configurations (the two halves pivot apart, about a point located above the number row, in increments of 7.5°). Subjects were exposed to a total of four typing conditions, one control (normal) condition, and three changes to the control condition. The elements that made up the control typing condition and the three test conditions are presented in Table I. Two of those test conditions, the request for fast-as-possible (yet still accurate) typing, and the use of an alternative letter arrangement, were expected to result in some deviation from normal typing speed. The third change, use of the keyboard in the split configuration (15 or 22.5° depending on subject anthropometry), was not expected to impact typing speed. In all but the fast condition, subjects were instructed to type at their normal typing pace, the one they would produce if they were transcribing a paper or letter. This was referred to as their preferred speed.

TABLE I. Elements of Typing Conditions

Test Condition	Elements: Typing Material	Keyboard Setup	Typing Speed
Control	text	closed	self-selected
Fast	text	closed	external influence
Split	text	open	self-selected
Letters	letters	closed	external influence

Instead of requiring subjects to learn the alternative letter arrangement and asking them to switch between the alternative arrangement and the traditional QWERTY system, letters in the text material used in the study were rearranged for the alternative system. Flannery et al.[17] employed a similar technique in their research on two alternative letter arrangements. For example, in the alternative system used in the current study the "f" and "r" were switched. Typing "for" in the alternative system required the same motions as typing "rof" on the QWERTY layout. Subjects were essentially typing letters rather than words in the alternative condition, which resulted in decreased typing speeds. Essentially, then, in this study subjects typed at speeds that could be categorized as preferred, faster-than-preferred, or slower-than-preferred.

Similar to the workplace subjects, laboratory subjects were given 10 minutes to acclimate to each change in typing condition. Additionally, at an earlier date subjects had typed under each condition in a practice session, during which they had been introduced to the test protocol and apparatus. Unlike in the workplace study, however, laboratory subjects knew when data samples were collected. Prior to each 6-sec collection they were told which sentence to type, and they were required to report on their accuracy afterwards. Sentences with errors were retyped.

Data Analysis

There were no differences in the processing of data from workplace and laboratory subjects. Three force statistics, average peak key strike force, 95th percentile force, and cumulative force normalized to 1 hr, will be used to characterize the relationship between typing speed and force. Average peak force refers to the statistical mean of the peak forces registered for each letter typed within a 6-sec sample. The 95th percentile force characterizes the upper range of force exerted on the keyboard, while being more stable than a single point absolute peak value. To provide additional stability, rather than using the single data point at the 95th percentile, all data points lying between the 94th and 96th percentiles were averaged together to produce the estimate of the 95th percentile value. Cumulative force refers to the area under the force-time curve and is presented normalized to a 1-hr period of continuous typing. Cumulative force has units of both force and time, to describe not only the amount of force exerted, but also the duration of the exertion. Units are similar to those used by Moore et al.[12] in describing cumulative tendon force. If a subject did not type for the full 6 sec, data were analyzed only for that portion of the time during which the subject typed. A sample of key strike force data, from one of the laboratory subjects, is presented in Figure 1.

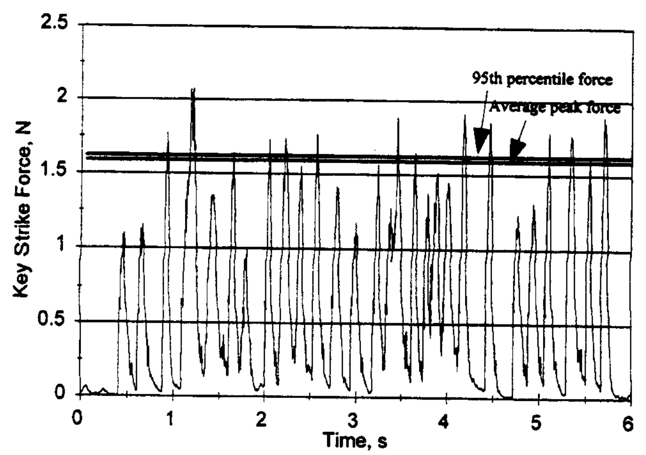

FIGURE 1. Example of key strike force data

Typing speed was calculated from force records, based on the amount of time between the first and last key strikes and the number of key strikes typed within the sample. The number of key strikes was converted to words per minute (wpm) by assuming the standard word equivalent of four letters and one space. A two-step heuristic process, employing a computer algorithm and visual inspection, was used to estimate the number of key strikes in each sample.[13] The process was designed to work with distinct key registration, as well as double and triple key strikes, which sometimes occur when a typist strikes a common series of keys in rapid succession, such as "er" or "the."

Typing speed and force statistics were calculated for each sample from each subject. For Data Set 1, subjects' average values were calculated for each statistic across samples for each subject, and then across subjects. Since subjects in this data set typed on their own keyboards, force data were also examined normalized for keyboard activation force. For Data Set 2, average values were calculated for each statistic across samples and within and across conditions for each subject.

RESULTS

Data Set 1

Typing force and speed statistics for the workplace group are presented in Table II. Relationships between typing speed and the three force statistics were examined across subjects to determine if greater typing forces were inherently associated with faster or slower typing speeds. Correlations from linear regression analyses between typing speed and average peak force, 95th percentile force, and cumulative force were 0.17, 0.37, and 0.68, respectively. Although the correlation between typing speed and cumulative force was less than 0.7, that model was significant ($p<0.001$).

TABLE II. Force and Typing Statistics for Professional Keyboard Operators (Means and Standard Deviations, Data Set 1, n=24)

Statistic	Absolute Value	Normalized to Activation Force
Average peak key strike force	2.2 N (±0.7)	2.7 (±0.7)
95th percentile force	2.2 N (±0.6)	2.7 (±0.7)
Cumulative force	2.5 kN•s/hr (±0.8)	3.1 kN•s/hr/N (±1.0)
Typing speed	59 wpm (±16)	

No significant associations were found between typing experience and either typing speed or the force statistics. Force statistics normalized for activation requirements were also examined, but that process did not strengthen any of the force-speed relationships. Correlations with typing speed for normalized average peak force, 95th percentile force, and cumulative force were 0.14, 0.36, and 0.62, respectively. The regression model for typing speed and normalized cumulative force was also significant ($p<0.005$). Typing speed and force were also examined within subjects, to determine if force systematically varied with normal fluctuations in an individual's typing speed. Frequency distributions of individual subject correlations between typing speed and the three force statistics appear in Table III.

Data Set 2

Typing speed and force statistics for the five experimental subjects appear in Table IV. Correlations between typing speed and the

TABLE III. Frequency Distributions of Within-Subjects Correlations Between Typing Speed and Force Statistics for 24 Professional Keyboard Operators (Data Set 1)

	Correlation Ranges					
Force Statistic	**−1 to −0.7**	**−.69 to −0.4**	**−0.39 to <0**	**0 to 0.39**	**4 to 0.69**	**0.7 to 1**
Average peak force	0	2	6	11	4	1
95th percentile force	0	0	7	9	7	1
Cumulative force	0	0	0	6	12	6

three force statistics, calculated across typing condition, appear in Table V.

Two subjects, S4 and S5, demonstrated significant relationships, based on linear regression models (p<0.001), between typing speed and average peak key strike force, with correlations

TABLE IV. Ranges of Average Force and Typing Speed Statistics for Experimental Subjects (Data Set 2)

	Experimental Condition			
Statistic	**Control**	**Split**	**Fast***	**Letters**
Average peak key strike force, N	1.4–2.2	1.3–2.1	1.6–1.8	1.3–2.2
95th percentile force, N	1.6–2.2	1.4–2.0	1.6–1.9	1.3–2.0
Cumulative force, kN•s/hr	2.2–2.9	2.0–2.6	2.3–3.0	2.0–2.2
Typing speed, wpm	48–76	40–75	61–84	32–57

*Due to problems at the time of data collection, only four subjects' data are represented in the Fast condition.

of 0.57 and 0.66, respectively. Significant (p<0.001) relationships between the 95th percentile statistic and typing speed were demonstrated by S2, S3, S4, and S5, and by all subjects between cumulative force and typing speed. However, these relationships were not all simply due to the variations of force statistics with typing speed. Some were due to the influence of test condition. For example, Figure 2 depicts the relationship between average peak key strike force and typing speed for S5. Condition information is added to that graph in Figure 3, in which it can be seen that average peak key strike force was similar for the two preferred speed conditions (control and split), greater for the faster-than-preferred condition, and reduced for the slower-than-preferred condition. For S5, an analysis of covariance with average peak key strike force as the dependent variable, typing condition as the independent variable, and typing speed as the covariate resulted in a correlation of 0.91, with condition and typing speed p-values of <0.001 and 0.80, respectively. Condition was, however, not always a significant factor, particularly in terms of cumulative force. Analyses of covariance for the three typing statistics are presented in Table VI.

Table V. Correlations Between Typing Speed and Force Statistics for Experimental Subjects (Data Set 2)

	Force Statistic		
Subject	**Average Peak**	**95th Percentile**	**Cumulative Force**
S1	0.02	0.53[A]	0.83[B]
S2	0.38	0.66[B]	0.83[B]
S3	0.26	0.78[B]	0.87[B]
S4	0.57[B]	0.86[B]	0.89[B]
S5	0.66[B]	0.82[B]	0.90[B]

[A]p<0.01
[B]p<0.001

DISCUSSION

Through these studies, circumstances were identified during which relationships between typing speed and key strike force statistics were evident. In general, in the workplace study, in which subjects typed at self-selected (preferred) speeds, average peak force and 95th percentile force were not found to vary in any consistent or predictive manner with variations in typing speed, either within or across subjects. Across subjects, a modest positive relationship was found between cumulative force and typing speed. Only a quarter of the workplace operators displayed strong within-subject relationships ($|r|\geq 0.7$) between cumulative force and typing speed, yet all of those were positive relationships ($r>0$).

In the experimental study, subjects typed at preferred speeds, as well as faster and slower than preferred speeds. No subjects demonstrated inverse relationships between typing speed and force, while some demonstrated strong positive associations between force and speed. This may be important when operators type under deadline or other potentially faster-than-preferred conditions, because actual force exposures may exceed predictions if no relationships are assumed to exist between speed and force, or if force is expected to decrease with increasing speed. The lack of association during preferred speed typing leads to the impression that there is no inherent connection between fast typing and forceful typing. Fast typing can be produced by operators generating a range of forces. As such, future research may seek to determine whether operators who tend to exert excessive force can be trained to use less force without sacrificing typing speed.

Cumulative Force

Cumulative force, an alternative method for assessing repeated exertions of force, deserves additional thought and investigation.

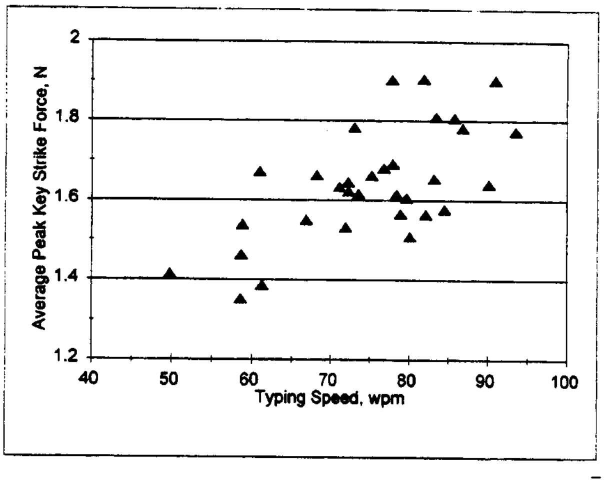

FIGURE 2. Average peak key strike force as a function of typing speed, from S5, experimental protocol

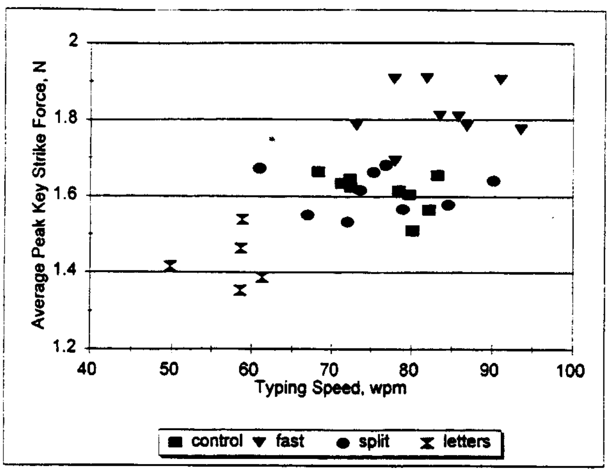

FIGURE 3. Average peak key strike force as a function of typing speed and typing condition, from S5, experimental protocol

This value may be calculated in different ways. In the current study cumulative force was calculated as the area under the force-time curve. As such, the units included both force and time. A previous report of cumulative keying force was apparently calculated by simply multiplying peak key strike force, typing speed, and number of work hours.[14] Such a simplified method ignores the temporal pattern of force exertion, though it is certainly a quicker calculation than the one proposed in the current study. The benefit of the more complex method is that cumulative force calculated in this way can be compared with cumulative force from other typing studies and from other types of hand-intensive work. Such task-independent exposure assessments may ultimately lead to an improved understanding of the relationship between force and upper extremity work-related disorders.

The association between cumulative force and typing speed should also be explored further. There is the potential for a positive relationship to exist between the two variables simply because there are more key strikes recorded for a given amount of time. However, this would only be true if the temporal pattern of the key strike force remained the same as speed increased, and only the interstrike interval was reduced. The more likely scenario is that both the interstrike interval and the force-time relationship change with changing speed. 95th percentile force did vary with typing speed in the second study, which would support the second hypothesis.

Web of Causality

Force exposure is only one strand in the web of causality of upper extremity musculoskeletal disorders. In fact, a recent article by Armstrong et al.[18] outlined the necessity for exploring intervening variables, those closer to the actual injury mechanism, such as muscle activity. Yet these are sometimes methodologically difficult to explore, especially outside a controlled environment. However, direct associations between external factors (key strike force and finger joint posture) and intervening factors (finger muscle activity and finger joint load) have been demonstrated through biomechanical modeling.[16,19] Harding et al.[19] developed their model for the expressed purpose of providing recommendations for key strike finger postures that would minimize joint loads and muscle activity.

Study Limitations

The limitations of the workplace study include the potential for interference or influence from test apparatus or the presence of observers on typing style or typing speed, even though subjects were requested to type normally. Steps taken to counteract those potential influences included collecting samples without the subjects' knowledge, collecting data over an extended period of time, providing an acclimation period prior to data collection, and informing subjects that typing speed was not being judged.

Limitations of the laboratory study included the potential interference or influence from test apparatus and the laboratory setting. Steps taken to overcome those influences included the provision of a separate practice session, conducted prior to the day of data collection, and acclimation periods prior to each new test condition. An additional limitation was the small number of subjects in the study. Trends observed in the data from this study should be confirmed with a study on a larger sample of typists.

Table VI. Results of Analysis of Covariance[A] for Force Statistics with Typing Condition as Independent Variable and Typing Speed as Covariate, Experimental Subjects (Data Set 2)

	Force Statistic								
	Average Peak			95th Percentile			Cumulative Force		
Subject	R	P_{cond}	P_{speed}	R	P_{cond}	P_{speed}	R	P_{cond}	P_{speed}
S1	0.59	p<0.05	NS[B]	0.58	NS	NS	0.86	NS	p<0.005
S2	0.87	p<0.001	NS	0.83	p<0.05	NS	0.91	p<0.05	p<0.001
S3	0.65	NS	NS	0.85	NS	p<0.005	0.87	NS	p<0.01
S4	0.84	p<0.001	NS	0.94	p<0.001	p<0.001	0.91	NS	p<0.001
S5	0.91	p<0.001	NS	0.94	p<0.001	p<0.05	0.92	p<0.05	p<0.001

[A]Multivariate general linear hypothesis (MGLH) procedure in SYSTAT, which produces results in terms of a model R, and p-values for significance of treatments and covariates. Interaction between treatment and covariate were not found to exist.
[B]NS= not significant at p<0.05

CONCLUSIONS

The relationship between key strike force and typing speed was explored in an observational study of professional keyboard operators on-the-job and in a sample of touch typists in a controlled laboratory experiment. Results from the two studies taken together show that there is generally no relationship between force and speed when subjects typed at self-selected (preferred) typing speeds, with the exception of the moderate relationship across subjects for cumulative force normalized to 1 hr. Generally, relationships were evident between force and speed when subjects typed over a range of speeds that included preferred and externally elicited, nonpreferred speeds.

No conclusions about the relationship between activation force and key strike force should be drawn from these studies, since it was not an experimental treatment, and since no subject typed on more than one keyboard.

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