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Final Report

Developing an Instrument to Measure Personal Keyboarding Style (K01 OH007826-03)

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List of Terms and Abbreviations

CART	Classification and Regression Tree (CART) is a statistical methodology which is a binary, recursive partitioning model which can be used to develop a decision tree model for prediction. It has become a popular data exploration alternative to regression, discriminate analyses, and other methods based on algebraic models
Content validity	"the degree to which the items in an instrument adequately reflect the content domain being measured" [1] (p. 866)
Concurrent-criterion validity	"the degree to which the outcomes of one test correlate with outcome on a criterion test when both tests are given at relatively the same time." [1] (p. 865)
Delphi technique	The Delphi Technique is used to develop consensus among a group of experts at a distance from each other. The general structure of the Delphi Techniques is for a small team to design a questionnaire which is sent to a larger respondent group. After the questionnaire is returned the monitor team summarizes the results and from these develops the consensus on the topic.
DIP joint	Distal interphalanggal joint
Discriminate validity	"the degree to which an instrument yields different results when measuring two different constructs; that is, the ability to discriminate between the constructs." [1] (p. 867)
Hyperextended MCP joints	The MCP joint (knuckle) is extended past zero degrees such that the finger is higher than the back of the hand
ICC	Intra-class correlation coefficient a statistical methodology used to determine the reliability of data
Inter-rater reliability	"the degree to which two or more raters can obtain the same ratings for a given variable" [[1]](p. 870)
Intra-rater reliability	"the degree to which one rater can obtain the same ratings on multiple occasions of measuring the same variable" *[1]* (p. 870)
Isolated thumb	While typing, the computer user holds the thumb in an adducted posture either at or above the palm level
Isolated little finger	While typing, the computer user holds the little finger in an extended/abducted posture
Kinematics	A field of study that works to describe the motion of objects. In people this would include the postures and speeds during tasks
K-PeCS	Keyboard – Personal Computer Style instrument
MCP joint	Metacarpophalangeal joint (knuckle)
MSD-UE	Musculoskeletal Disorders of the Upper Extremity is a term used to refer to a constellation of diagnoses related to the musculoskeletal and nervous systems that are believed to be caused by repetitive tasks, forceful exertions, vibrations, mechanical compression (pressing against hard surfaces), or sustained or awkward positions.
PIP joint	Proximal interphalangeal joint
Psychometrics	The reliability and validity of an instrument
Pronation	Rotating the forearm so that the palm faces down
Supination	Rotating the forearm so that the palm faces up
Ulnar deviation	Movement of the hand towards the little finger
Wrist/hand displacement	Translational hand movements in which the entire hand/wrist unit is repositioned to strike the keys

Abstract

Although the incidence of computer-related musculoskeletal disorders of the upper extremity (MSD-UE) is relatively small [2] when compared to repetitive industrial jobs, the number of workers using a computer at work is large and growing [3] making computer use a significant risk factor for worksite injury. Therefore, the ability to prevent computer related injuries should be a priority for occupational health personnel. To be able to prevent injuries, there must be an easy, reliable, and clinically relevant method to describe and measure postures and behaviors during computer use that are considered to be risk factors for the development of MSD-UE. Although there are several generic observational methods to evaluate upper extremity work [4, 5] there is no a reliable and valid observational instrument that can be used in the workplace to document and assess the parameters of keyboarding that may be risk factors for MSD-UE.

This project's overall aim was to develop and refine an observational instrument, the Keyboard – Personal Computer Style instrument (K-PeCS), which had the ability to document postures and behaviors identified as risk factors for MSD-UE. For this project we developed the K-PeCS in two phases. The specific aim of Phase I was to develop the K-PeCS and refine the psychometrics of the instrument including content and concurrent criterion validity, and inter-rater and intra-rater reliability. The specific aim of Phase II was to develop a model using K-PeCS items that could discriminate between those with and without MSD-UE.

To accomplish our aim in Phase I we first developed the content validity of the K-PeCS instrument. Risk factors for musculoskeletal disorders of the upper extremity (MSD-UE) that could be related to keyboard use were identified from the literature and from expert opinion. Items for the K-PeCS were developed and sent to seven experts who rated the items for validity and operationalization. Based on these ratings, items were included or excluded from the K-PeCS [6].

Once K-PeCS items were identified and operationalized we digitally video recorded 45 keyboard users, and simultaneously obtained the kinematics of their hands using a 3 dimensional motion capture system. To ascertain the inter-rater reliability of the K-PeCS, 3 trained raters independently rated video clips of these 45 computer users. To ascertain intra-rater reliability the same raters re-rated a sub-sample of 15 video clips one week later. The ratings were assessed using intraclass correlation coefficients (ICC). The overall K-PeCS had excellent reliability (inter-rater: ICC = .90; intra-rater: ICC = .91). Most individual items had from good to excellent reliability, although three items fell below ICC = .70. To assess concurrent criterion validity we compared the ratings obtained on the K- PeCS to the 3 dimensional motion capture results. Those K-PeCS items that were assessed for concurrent validity compared favorably to the motion capture data for all but 2 items [7]. Thus, at the end of Phase I we had ascertained that the K-PeCS was a reliable and valid measure of keyboarding postures and behaviors.

To accomplish Phase II, we obtained digital video recordings of 42 subjects as they worked at their own computer workstation: 21 subjects had a diagnosed MSD-UE (cases) and 21 matched subjects were without MSD-UE (controls). The K-PeCS items were rated from a video clip by an expert rater blinded to subject status.

The ratings from the 42 worksite subjects were used to generate models to discriminate between cases and controls using Classification and Regression Tree (CART) methods. From these analyses a CART model was generated which could accurately discriminate between cases and controls when the cases had any diagnosis of MSD-UE (69% accuracy). The model had the single item, "neck flexion angle greater than 20 degrees"; subjects who did not have a neck flexion angle of greater than 20 degrees were accurately identified as controls [8].

The results of this study indicate that the K-PeCS is a reliable and valid instrument that can be used in the workplace to document the postures and behaviors of computer users. The K-PeCS can be used in two ways in the workplace. Due to its observational nature, and the selection and criterion of the items, clinicians who assess computer workstations to prevent injury or provide reasonable accommodation for an existing injury can use the K-PeCS to assess computer workstations and develop interventions. In addition, since the KPeCS is a highly portable and reliable tool, it can be used as an outcome measure for research studies examining the effect of interventions in the workplace.

Highlights/Significant Findings

The aim of the project was to develop a psychometrically sound observational instrument to measure keyboarding postures in the workplace and which showed the ability to discriminate between those with and without MSD-UE.

During the course of the project we successfully developed the Keyboard – Personal Computer Style (K-PeCS) instrument. The K-PeCS is a 19-item criterion-based instrument which documents stereotypical postures and behaviors during computer keyboarding. It demonstrates good overall inter and intra-rater reliability (inter-rater: ICC = .90; intra-rater: ICC = .91) as well as good content and criterion related validity.

The K-PeCS demonstrates the ability to accurately discriminate between those with and without any type of MSD-UE (69% accuracy) with a single item, "neck flexion greater than 20 degrees." Those with less than 20 degrees of neck flexion were not generally those with MSD-UE

See appendix A for a copy of the K-PeCS and a copy of the K-PeCS manual.

Translation of Findings

There have been many excellent research studies examining keyboard users' mean postures and behaviors using direct methods to obtain data [9-12]. Direct methods measure keyboarding kinematics by applying a measuring device, such as an electric goniometer or motion analysis device, to keyboard users' extremities while they are typing. This method can provide very accurate and detailed descriptions of typing but require a great deal of highly technical equipment. This is problematic for many occupational safety personnel for several reasons: most occupational safety personnel do not have access to this type of equipment, making it infeasible for them to use these methods to obtain data and therefore directly compare their results to the literature; studies using direct methods are almost always completed in a laboratory, where the equipment can be easily set up and used. Laboratory set-ups tend to be standardized to the subjects' anthropometrics, and therefore are "ideal" workstation set-ups, promoting neutral postures. Even if subjects are instructed to set-up the laboratory workstation to match their own workstations, few appear willing or able to manipulate the laboratory office equipment to mimic their worksite set-up. This makes the results of laboratory studies less applicable to "real world" interpretations. Finally the data generated using direct methods requires extensive data processing to make it interpretable to the average occupational safety personnel. Thus, the information generated by direct methods is often not feasible or useful for occupational safety personnel attempting to evaluate and intervene with workers in the workplace. Observational methods, those which use observation of subjects without the direct application of measuring equipment, provide more familiar and worksite applicable results. Until the instrument described in this report had been completed, occupational safety personnel had no systematic, easily interpretable, valid and reliable method to evaluate keyboard users in the work place.

In this study we developed the K-PeCS an instrument that is easily used in the workplace and can provide valid, reliable and results interpretable at the worksite which could be used to develop intervention strategies to reduce the postures and behaviors hypothesized to cause MSD-UE. The K-PeCS will allow occupational safety personnel to document the types of postural behaviors which occur during keyboard. This will encourage accurate identification of client specific problem areas, which will allow occupational safety personnel to more efficiently and effectively implement interventions which can reduce potential risk factors. In addition occupational safety personnel can re-assess the success of their interventions by re-evaluating keyboard users' postural behaviors after the intervention has been completed. The use of a standardized observational method to ascertain and document keyboard style has the potential to improve the overall practice of office worksite intervention.

An additional benefit of the K-PeCS is that it has been shown to be psychometrically sound. It therefore can be used by research personnel as a method to document worksite keyboarding postures and behaviors as an outcome measure.

Outcomes/Relevance/Impact

The results of this project have the potential to impact the computer using population's risk for developing MSD-UE. In this project we developed the Keyboard – Personal Computer Style instrument (K-PeCS). The KPeCS is a psychometrically sound instrument which demonstrates good to excellent reliability, as well as construct, criterion, and discriminate validity. This project has lead to potential improvements in occupational safety and health by providing an instrument that can systematically document worker specific postures that may put them at risk for MSD-UE while they use a computer keyboard, help to identify potential interventions to reduce those risky postures, and document the effect that these interventions have on these postures. Using the K-PeCS will help occupational safety personnel to provide a more comprehensive and evidence-based intervention to computer workers.

We were able to use items of the K-PeCS to discriminate between a small sample of workers with and without MSD-UE. This suggests that the K-PeCS has the potential in the future to be a predictive instrument that can be used to develop models of keyboarding styles which place workers at risk for MSD-UE. With the development of these models, occupational safety personnel will have the ability to more accurately apply worker specific interventions.

A secondary benefit to the development of, the K-PeCS is that it can be used as an outcome measure by researchers to document computer work styles in the work place. Until now, it was difficult to measure specific keyboard behaviors in the workplace because there was no standardized method to do so. With the K-PeCS researchers will have a valid and reliable outcome tool to evaluate population based interventions.

Finally, while developing the criterion-related validity, we had to develop models which used direct measures of keyboarding style using 3-dimensional motion capture. The models developed for this study were primarily of the finger and hand postures, an aspect of typing which has received little attention in the literature. This project has therefore contributed to the knowledge about hand and finger postures during keyboarding including the development of a new construct in typing, wrist/hand displacement, as well as documentation of postures that have been described previously, isolated little finger and isolated thumb. These postures appear to have the potential to be additional risk factors for MSD-UE, although further research is necessary to determine this.

Scientific Report

Background

Prevalence and incidence of MSD-UE in computer users

Musculoskeletal disorders of the upper extremity (MSD-UE) are a significant problem for the United States workforce. The Bureau of Labor Statistics (BLS) has reported that 34% (582,300 cases) of all illnesses and injuries involving days away from work for 1999 were due to repetitive motion [13] and that of these 9% were related to illnesses of the upper extremity [14]. This percentage probably underestimates the magnitude of the problem [15]. The median length of time spent off of work in 1999 due to repeated trauma disorders was 27 days for carpal tunnel syndrome and 9 days for tendonitis [16]. Total costs associated with MSD-UE run as high as $54 billion, 0.8 percent of the nation's gross domestic product [15].

Computer use has been linked to MSD-UE and musculoskeletal pain since the mid 1980's [17]. Continued study of the association over the last 20 years has found a moderate association between computer use and both MSD-UE and musculoskeletal pain [18]. The prevalence and incidence of MSD-UE related to computer users has been identified in several studies and has been summarized in Table 1.

Table 1 – Prevalence and incidence of musculoskeletal disorders among computer users

	Prevalence rates		Incidence rates	
	n/s	a/h	n/s	a/h
Hales et al. (1994)[191	9.0%	12.0%		
Berqgvist et al. (1995)1201	23.4%	8.7%		
Gerr et al. (2002)[21			21.1%	13.9%
Rempel et al. (2006)[211			44.2%	17.5%

n/s = neck/shoulder disorders; a/h = arm/hand disorders

Although the incidence of computer related MSD-UE is small compared to other industrial jobs, it remains a serious concern as the number of people using a computer at work continues to steadily rise. In 1993, 45.8% of all workers used a computer, by 1997 use had risen to 49.8% [22], and by 2001 to 53.5% [3]. That computers are becoming ubiquitous in the workplace should make developing methods to prevent MSD-UE in computer users a priority for occupational safety personnel.

Risk factors for MSD-UE

Many studies have focused on the associations between postures and MSD-UE [23]. Abnormal postures are hypothesized to put increased forces such as friction and shear on tendons and tendon sheathes [24-28]. Forearm pronation, wrist extension, wrist flexion, and ulnar deviation also increase carpal tunnel pressure [29-32] which has been hypothesized to increase the risk for tendonitis [33]. Although there is great variety in preferred postures among different keyboard users [11, 12, 341 research suggests that individual keyboarding kinematics are relatively stable and unchanging during keyboarding tasks [35, 36].

The following summarizes the literature as it relates to computer use and body, arm, wrist, hand, and force. In general, the following body, arm, and wrist postures have been reported to be risk factors for MSD-UE in computer users:

- head tilt at greater than 20 degrees [4, 8, 37-39];
- shoulder flexion greater than 20 degrees [4, 40];
- elbow angle less than 80 degrees [4, 30, 32, 40, 41];
- Pronation angle less than 45 degrees [32] and greater than 80 degrees [30];
- Wrist ulnar deviation greater 20 degrees [37];
- Wrist extension angle greater than 15 degrees [4, 5];

Although body, arm, and wrist postures have been extensively examined, there is little research that has described common finger postures during keyboarding [9, 12], and even less that has examined the associations between finger postures and MSD-UE. Therefore, the optimal overall finger posture has not been clearly identified. Nelson et al. [42] measured the tendon travel of the FDP and FDS while subjects typed on a keyboard set to a variety of different angular configurations. They reported that greater MCP flexion combined with smaller PIP and distal interphalangeal (DIP) flexion (i.e. typing with straight fingers) resulted in greater tendon travel. In this same study Nelson et al. compared one individual with the least tendon travel to one with the most tendon travel and reported that the individual with the least tendon travel had an average MCP flexion angle of 16 degrees combined with an average PIP flexion angle of 46 degree and a DIP flexion angle of 28 degrees. However, as these results are only using one individual, and the factors that cause increased tendon travel during typing are also dependent on the anthropometrics of the individual [42], these measurements can only provide an gross estimate of the optimal position of the finger joints. Research on the association between finger postures and MSD-UE has been descriptive in nature [43, 44]. This research suggested that hyperextended MCP joints, "isolated" digits (thumb and little finger) were present in people who had MSD-UE.

Table 2 provides a comparison of average postures with the postures that are considered to be optimal positions. It is clear, that in the wrist, except for wrist extension, the average computer user does not engage in postures which place him at risk for MSD-UE, but that a small proportion of computer users, as represented by the standard deviation, do exceed these specifications. For finger postures, however, the average computer user may be typing at a less than optimal position. Force is also risk factor associated with MSD-UE in computer users [43, 45]. Like postures, most individuals keyboarding tasks rarely exceed the risk level of 2-5% maximum voluntary contraction [46], but some individuals do.

Table 2 – Mean postures (±SD) during standard keyboard use

	Mean reported in the literature	Optimal
Wrist pronation*	64 ° ± 9.5°	45⁰ - 80°
Wrist ulnar deviation*	13 ° ± 7.5⁰	<200
Wrist extension*	190 ± 8.1°	<15°
Finger MCP flexion#	24° ± 7•9⁰	16°
Finger PIP flexion#	40° ± 7.0°	46°

mean calculated by taking the mean of left and right sides.
*[11] #[9]

This analysis of postures and forces suggest that while not all computer users engage in postures or forces that place them at risk for MSD-UE, a number of computer users do. Occupational safety personnel need to have a method to document potential risk factors when assessing a computer user's workstation to determine if they are engaged in behaviors that put them at risk for MSD-UE. This method must be valid and reliable, be capable of being used at the worksite and able to provide them with easily interpretable information to assist with developing and implementing interventions to reduce risk. Researchers, too, need a method to document keyboard postures and actions which can be used at the computer user's workstation, and can be used to document outcomes in computer ergonomics' studies.

Several methods have been developed to assist with the measurement of job tasks (See Li & Buckle [47] for a review of methods). These can be broadly categorized as direct and observational methods. Direct methods involve attaching a device to a worker, such as a sonar device, electric goniometer, LED, or electrode to record the data. Direct methods tend to be more precise, require more equipment, and be less readily translated into real world interventions than observational methods. In observational methods, the worker is generally observed, without any interference from the researcher. Observational methods tend to be less precise [48], but provide more clinically interpretable information. Ideally, both types of analysis would be used to evaluate a job task. However, this is often not feasible. Several observational methods to evaluate upper extremity work are described in the literature including: [4, 5, 38, 49-52]. While many of these evaluate wrist and body postures, none evaluate hand postures and motions, although two evaluate grip strength [5, 52]. Only two assess computer use specifically [38, 51], and neither have had extensive psychometric testing.

Summary

The incidence of computer related MSD-UE appears ranges for between 20 to 40% although computer use falls in the low risk job category. MSD-UE risk factors associated with computer use are repetition, force, and posture. Although many keyboard users never appear to place themselves at risk, however, the keyboarding style of some computer users puts them in a high-risk category. Sommerich et al. [12] concluded "From the current study, it would seem that individual style may play a significant role in the biomechanical profile of a given typist." (p. 51). Feurstein et al. [45] also stated: "These findings suggest that how an individual performs a work task may have a greater effect on force exerted during keyboarding than the specific design characteristics..." (p. 1145). These researchers suggest that an individual's postures and behaviors during keyboarding, that individual's personal keyboarding style, may be an important risk factor for MSD-UE.

Personal keyboarding style, therefore, appears to an important factor in the relationship between MSD-UE and computer keyboard use. The aim of this research project was to develop and refine an observational instrument – the Keyboard - Personal Computer Style instrument (K-PeCS) which can be used to identify and evaluate parameters of personal keyboarding styles that may be related to MSD-UE. The specific aims of this project were: 1) to evaluate inter- and intra-rater reliability and the content and concurrent criterion-related validity of the K-PeCS; 2) to use information gathered using the K-PeCS to develop a model which could discriminate between those with and without MSD-UE.

Methods

The development of the K-PeCS was divided into 2 distinct but interrelated phases. In Phase I we developed the K-PeCS and refined its psychometrics. Phase I was sub-divided: In Phase Ia we developed items for the K-PeCS; in Phase Ib we tested these items for inter and intra-rater reliability; in Phase Ic we evaluated the concurrent criterion validity. In Phase II we developed a model which could discriminate between those with and without MSD-UE. The following sections will describe the methodology and results of each of these Phases.

Phase Ia – Developing Content Validity

Method: From the literature review we developed K-PeCS items which we thought could be measured reliably using observational methods and that were potentially risk factors for MSD-UE.

The items were further expanded and focused through discussions and ratings by experts both in biomechanics and hand therapy. The first version of the K-PeCS (beta-1) had 21 items. The items were operationalized to develop a standard method of describing and measuring them.

To further refine the items we used the Delphi technique [53] on the K-PeCS (beta 1) with seven experts, three certified hand therapists, and four ergonomists whose research field was in MSD-UE [54]. To use the Delphi Technique, each rater was provided with the items of the K-PeCS (beta-1). They were asked to evaluate each item using a likert-style scale for each of the following parameters: 1) The likelihood that the item was a risk factor for MSD-UE; 2) The biomechanical or epidemiological basis for that item as a risk factor for MSD-UE; 3) Whether the operationalization of the K-PeCS measured the item of interest; and 4) The clarity of the operationalization in identifying the item of interest.

Data Analysis: Intraclass correlation coefficients (ICC's) [55] were calculated for the ratings of each separate item's risk factor and rationale combined to establish the agreement between raters concerning that item's importance as a risk factor for MSD-UE, and between the operationalization and the clarity of the operationalization to determine the agreement between raters concerning how well that item was operationalized. Means and standard deviations were then calculated. Any item with in which the mean rating of risk was less than 1.0, or any item in which risk rating equaled 1.0 and the rationale rating was less than or equal tol .0 were excluded from the final K-PeCS.

Results:

There was general agreement among the experts that the items' operationalization and clarity were good. Only in rating items on pronation and key activation force did raters express some doubts about the operationalization. Ratings for clarity were also generally high. Only hand movement appeared to be relatively unclear to raters.

Based on the mean ratings we initially planned to eliminate six items (hand position symmetry, continuity of typing, # of fingers used, space bar activation, changes in radial angle, and isolated thumb). Any item with a low ICC was examined to determine the reason for low rater agreement. If there was a great deal of variation between raters, this might indicate that an item should not be kept, even if it met the previous inclusion criteria. We found that the low agreement was generally caused by a highly differing score from a single expert for each item. We therefore included the two items which met our inclusion criteria (bouncing wrists, key activation force), and excluded the two items which did not meet the inclusion criteria (hand position symmetry, continuity of typing). The item related to thumb isolation was initially to be removed from the instrument, but was reinstated after discussions with the experts about these results. In addition the # of fingers used was reinstated as a marker for touch typing. An item related to neck posture suggested during the feedback process was also added. See [6] for a more in-depth discussion of the development of the content validity of the K-PeCS

K-PeCS Instrument

From the above examination of content validity we developed the final K-PeCS which is a 19-item rating instrument that documents the frequency of stereotypical motions and postures that are used by computer keyboard users during routine keyboarding tasks. Many of the items are divided into right and left side measurements, and for the digit postures, they are also broken down by digits 2 through 5. This allows for more concise identification of body and hand postures. K-PeCS items (Table 3) can be divided into 3 general categories: items of static posture in which the keyboard user's postures remain essentially unchanging *(items* 1, 3, 4, 5); items of dynamic posture (frequencies) in which the keyboard user periodically assumes a posture thought to be a risk factor for MSD-UE, but does not necessarily maintain that posture throughout the task *(items 8, 10, 11, 12, 13, 14, 15, 16, 17, 18,* 19); and items of force and tension which describe keyboard activation forces and the use of supports *(items 2,* 6, 7, 9). For all items the rater observes the keyboard user or a video of the keyboard user and determines which criterion for each item best matches the user's keyboarding style.

Table **3 -** Items and outcomes being measured by the K-PeCS

#	Item	What the item rates	Criterion
Items of Static Posture			
1	Torso angle	The angle of the keyboard user's torso to the horizontal plane	>105° 900-1050 <900
3	Neck flexion angle	The displacement angle & position of the head	<10° 11°-20° 21° -30 ° >30°
4	Shoulder flexion angle	The flexion angle of the shoulders	0-20° 210350 >350
5	Elbow flexion angle	The flexion angle of the elbows	<79° 79° -120° >120°
Items of Dʸnamic Posture			
8	Wrist/hand displacement	The frequency with which keyboard users move their hands while typing	Occ oft mst/time
10	Wrist ulnar angle	The frequency with which keyboard users exceed 20° of ulnar deviation	nev occ freq alw
11	Wrist extension angle	The frequency with which keyboard users exceed 15° of wrist extension	nev occ freq alw
12	Forearm rotation	Whether keyboard users change the rotation angle of their forearm	yes no
13	Isolated 5`" digit	The frequency with which keyboard users isolate the little finger	nev occ freq alw
14	Isolated thumb	The frequency with which keyboard users isolate the thumb	nev occ freq alw

Table 3 - Items and outcomes being measured by the K-PeCS

#	Item	What the item rates	Criterion	
15	# of fingers used to type	Number of digits used by keyboard users to strike the keys	1 dig 2 dig 3 dig 4 dig 5 dig	
16	Space bar activation	The finger used to strike the space bar	rt thmb rt ind other	
17	MCP hyperextextension	The frequency with which keyboard users hyperextend their MCP joints	3rd	nev occ freq alw
			4th	nev occ freq alw
			5th	nev occ freq alw
2	Back rest use	Whether keyboard users rest at least 2/3 of their back against the chair	yes yes/pau se no	
6	Forearm support use	Whether keyboard users support their forearms/elbows	yes yes rt/no lt yes lt/no rt no	
18	PIP/DIP curve	Whether keyboard user's PIP/DIP joints are curved (>25°)	3f°	yes no
			4th	yes no
			5th	yes no
19	DIP hypermobility	Whether keyboard users' DIP joints hyperextend when striking the keys	yes no	
Items of Force and Tension				
2	Back rest use	Whether keyboard users rest at least 2/3 of their back against the chair	yes yes/pause no	
6	Forearm support use	Whether keyboard users support their forearms/elbows	yes yes rt/no lt yes lt/no rt no	
7	Wrist support use	Whether keyboard users support their wrist	yes unsupp key supp pause no	
9	Force	The degree of force used to strike the keys	low mod high	

All items except 1; 2; 3; & 9 are measured on both the right and left sides; Items 17 & 18 are measured separately for digits 2 – 5; oft – often; nev – never; occ – occasionally; freq – frequently; alw – always; mst/time – most of the time; supp - supported; unsupp – unsupported, right – rt; left – lt; ind – index; thmb – thumb; key - kevboard

Phase Ib and Ic – Developing inter, intra rater reliability/ concurrent validity

To establish reliability, raters must rate the performance of one subject several times, thus the best method to complete observational reliability it to video record a performance and rate from the videos. To establish concurrent validity, observer-rated performances are compared to a "gold standard", in this case a directly measured kinematic performance. For this study, the "gold standard" kinematic performance was obtained using 3-dimensional motion capture (VICONTM)

Method: To obtain the video performance, we videotaped forty-five computer users between the ages of 18 and 65 who were recruited from faculty, staff, and students of the University of Pittsburgh. Subjects had to be familiar with using a computer and to be able to use a keyboard continuously for 20 minutes. Both expert and non-expert typists were recruited in order to obtain a variety of different keyboarding styles. The subjects' mean age was 33.1 years (±12.7). They were 71% female (32), 73% white (33), and 91% (41) right handed, with approximately half (24, 53%) reporting that they had touch typing training (expert typists). The mean hours of computer use a day was 5.3 (±2.7).

Procedure:

To obtain videos for concurrent validity assessment the subjects used a keyboard at a computer workstation set up in a laboratory in which a motion capture could be completed simultaneously with video capture. Although the desktop height remained at a constant 29" to standardize video and VICON™ camera angles, the subjects were allowed to adjust the chair to conform to their preferred workstation configuration. Subjects typed from an electronic keyboarding program, Typing Master Pro ™[1], which automatically advanced the text as the keyboard user progressed. This program also documented typing rate and speed.

Five digital video cameras were positioned around the subject, three with the field of vision focused on the wrists and hands only, and two positioned to capture full body movements. The VICON ™[2], a motion measurement system (VICON 612 system with 5 M2 cameras) was positioned around the computer workstation to capture 3 dimensional data. The hand, wrist, and digit movements were derived from tracking 42 passive markers positioned on the dorsal surface of both hands.

Data were collected in 3 1-minute trials of the synchronized VICON™ and video data spaced out over the second 10-minute time period. Only one minute of data acquisition was required as keyboarding is highly stereotypical [50, 56].

Data Processing and Data Analysis

Video recordings from one trial for each subject was digitized into a video movie (clip) that had all five views (right full body, right hand, left full body, left hand, and overhead). To assess inter-rater reliability 3 trained raters independently rated 45 clips with the K-PeCS. The three raters also rated a subset of 15 clips twice, with at least a week between each rating, to establish intra-rater reliability. Intraclass correlation coefficients (ICC) were used to calculate the reliability of each item and the overall K-PeCS instrument [55].

Concurrent validity was assessed for items # 8, 10, 11, 13, 14, 17, and 18 (see Table 3) on a sub sample of 15 subjects rated by the same rater. Data were first converted into angles as a function of time (for postures) or pathlengths (for hand displacement) using methods described elsewhere [57]. A program was developed in LabVIEW 7.1[3] to quantify equivalent values that could easily be compared to the raters' evaluations using the K-PeCS. A comparison was then made between the raters and the motion capture values using a non-parametric test, the Kruskal Wallis One-Way Analysis of Variance by Ranks Test, as the K-PeCS data were both ordinal and not evenly distributed. For our analyses the K-PeCS rating acted as the grouping variable for each item. We then looked to see if those subjects rated as "never" had a smaller summed ranking than those subjects rated as "occasional", and those rated "occasional" had a smaller summed ranking than those rated as "frequent", etc. If significance was achieved using the Kruskal Wallis, we completed Mann-Whitney U tests to identify which items were significantly different from each other.

Results:

The overall K-PeCS inter-rater ICC was 0.90 ($p < .001$), which indicates that the instrument, as a whole, had excellent reliability. The inter-rater reliability of individual items was generally above 0.70 ($p < .001$) which is indicative of good reliability [58] (See Table 4). Notable exceptions were force (*ICC* = 0.67; p <.001), isolated thumb (*ICC* = 0.63; p <.001) and hypermobility (*ICC* = 0.33; p <.001).

[1] Typing Master Finland, Inc., Helsinki, Finland - http://www.typingmaster.com/index.asp?go=company

[2] Vicon Motion Systems Inc, Lake Forest, CA, USA - http://www.vicon.com/jsp/`index.jsp

[3] National Instruments Corporation, Austin Texas - http://www.ni.com/

Intra-rater reliability was also excellent (*ICC* = 0.92; *p* <.001). A pattern of lower reliability levels for individual items was noted for some of the same items found to have poor inter-rater reliability: force (*ICC* = 0.67; p =.04) and isolated thumb (*ICC* = 0.62; p <.001) (Table 4).

Table 4: Inter-rater and Intra-rater reliability of the K-PeCS

#	Item	Inter-rater reliability (ICC)	Intra-rater reliability (ICC)
1	Torso angle	0.71	0.87
2	Back rest use	0.87	0.93
3	Head flexion angle	0.85	0.81
4	Shoulder flexion angle	0.93	0.96
5	Elbow flexion angle	0.95	0.93
6	Forearm support use	0.87	0.80
7	Wrist support use	0.94	0.94
8	Wrist/hand displacement	0.75	0.79
9	Force	0.67	0.67
10	Wrist ulnar angle	0.77	0.71
11	Wrist extension angle	0.89	0.87
12	Changes in pronation	0.85	0.83
13	Isolated 5th digit	0.90	0.87
14	Isolated thumb	0.63	0.62
15	# of digits used to type	0.91	0.83
16	Space bar activation	0.86	0.90
17	MCP hyperextension	0.93	0.94
18	PIP/DIP curve	0.89	0.73
19	Hypermobility	0.33	0.78

All p-values were significant at <.001

The K-PeCS also demonstrated adequate concurrent criterion validity. For most of the items, the mean ranking of the VICON™ score by K-PeCS criteria indicated that those items rated as occurring "never" were smaller than those rated as "occasionally", which were smaller than those rated as "frequently", which were smaller than those rated "constantly", or in the case of dichotomous ratings, the ranking of an item that did not occur was lower than the ranking of an item that did occur. The exceptions were for wrist ulnar deviation angle (p = .69), and isolated thumb (p = . 15). In these cases the rankings for two of the ratings were reversed; "never" and "occasionally" for wrist ulnar angle, and "occasionally" and "frequently" for isolated thumb. All items that had the correct ranking order also achieved significance, indicating that there was a significant difference between at least two of the rankings

See [7] for further details about reliability and concurrent validity.

Phase 11- Discriminate Validity of K-PeCS

Methods: Subjects were recruited from the University of Pittsburgh faculty and staff through a direct University mailing as well as through word of mouth. Cases had to have been diagnosed within the last 6 months with any MSD-UE that was believed to be associated with computer use [59, 60]. Controls were matched to the cases for age (±5 years) and gender. They could not have been diagnosed with MSD-UE within the last 5 years. Both cases and controls had to be between the ages of 18 and 65, and use a computer at least 20 hours per week. Subjects with a body mass index (BMI) above 30 were excluded from the study as obesity has been associated with MSD-UE [61, 62].

Subjects were observed at their own workstation using their own keyboard. Video data was obtained from lateral views of the right and left hand and from overhead. In addition the researcher took two lateral still photographs to obtain static body postures. A standardized paragraph was opened in the subjects' computer, and subjects were instructed to type this paragraph at their normal pace. The entire typing process took approximately 10 minutes to complete.

Data Processing: The video recordings were downloaded into video clips. Each clip contained the final 1-minute of typing for each of the right, left, and overhead views. A rater skilled in using the K-PeCS rated each of the clips twice, with a one week interval between the ratings. To prevent the rater from identifying if the clip was from a case or control the clips were coded and presented in a random order. The results of the two ratings were compared and discrepancies between the first and second rating period were reviewed and agreement as to the correct rating was reached.

Data Analysis:

Classification and Regression Tree (CART) analysis was performed. CART analysis provides both information on whether items can predict those with and without MSD-UE, and also provides details on how items interact. The CART methodology [63] for classification trees is a binary, recursive partitioning model which can be used to develop a decision tree model for prediction. It has become a popular data exploration alternative to regression, discriminant analysis, and other methods based on algebraic models [64].

As this was a small sample, we determined whether K-PeCS items could distinguish between those with MSD-UE (MSD) and those without MSD-UE (NOMSD) for any type of MSD-UE diagnosis. For all models we estimated the sensitivity, specificity, and accuracy. The sensitivity and specificity assist in interpreting the ability of a tree to distinguish those with MSD-UE (sensitivity) compared to the ability of the tree to identify those without MSD-UE (specificity).

Results: Subjects: Forty-two subjects [21 cases (MSD) and 21 controls (NOMSD)] were recruited. The sample was predominantly female (86%) with a mean age of 46.7 (±9.1). The self-reported hours of computer use were essentially the same between MSD (6.5 ± 1.6) and NOMSD (6.2 ± 2.5), as were the number of subjects trained in touch typing (MSD = 62%, NOMSD = 57%). MSD had a variety of different diagnoses; radiating neck syndrome, carpal tunnel syndrome, epicondylitis, tendonitis, tenosynovitis, and arthritis. The majority of them were for the wrist and hand.

Tree Model: Although several trees with multiple K-PeCS items were generated during the CART analysis, the tree which best predicted those who had MSD contained only a single item, neck flexion angle greater than or equal to 20 degrees (Figure 1 a). Model sensitivity was low (0.48) but specificity was very high; 90% of subjects who did not have MSD were correctly classified as NOMSD if neck flexion was 20 degrees or less. The percent accuracy of the model was 69%. Thus, only 2 NOMSD subjects out of 21 had neck flexion greater than 20 degrees. More detailed information on this study is available through [8] .

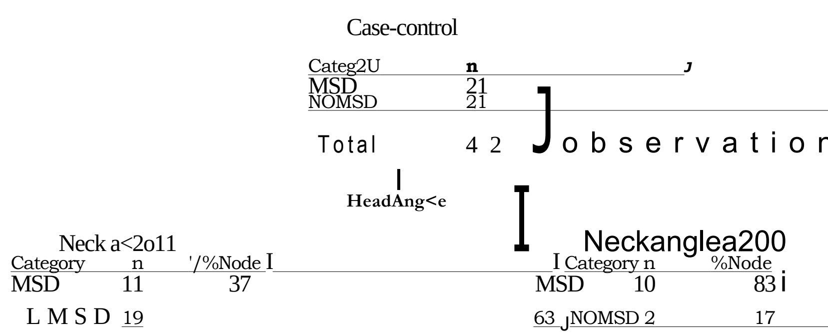

Figure 1 – CART tree which discriminated between those with and without MSD-UE

Discussion

The aim of this research project was to develop and refine an observational instrument – the Keyboard - Personal Computer Style instrument (K-PeCS) which can be used to identify and evaluate parameters of personal keyboarding styles that may be related to MSD-UE. To achieve this aim we had to first identify the appropriate content for the instrument. This content not only had to identify keyboarding postures and behaviors that were potential risk factors for MSD-UE, but also had to be measurable using observational methods. To accomplish this we used a structured method which combined literature review and expert opinion to develop the items of the K-PeCS.

Once we had items, we had to ensure that they could be rated reliably both by one rater repeatedly and by several raters. To do this we obtained video recordings of subject's keyboarding and had trained raters rate keyboarding style. These raters were able to obtain good to excellent reliability for most items of the K-PeCS. From this we estimated the inter- and intra-rater reliability and determined that the K-PeCS could be used to reliably measure postures and behaviors during keyboard use. This indicates that the K-PeCS can be used reliably identify how a worker is interacting with their keyboard and these will be an appropriate indication of their potential risk for MSD.

Our evaluation of concurrent validity suggests that the K-PeCS is measuring the kinematics of keyboard performance accurately. Since the K-PeCS measures are similar to the gold standard of 3-dimensional motion capture, we can be fairly confident that using K-PeCS will provide a reasonable determination of the motions and actions of a keyboard user. While the K-PeCS can never be as precise as motion capture, it has advantages over this more direct measuring system. The K-PeCS can provide a reasonably accurate picture of a person's keyboarding style while at the person's actual workstation. The assessment takes less than 10 minutes to complete and is immediately interpretable, without additional data analysis or manipulation of material.

An important aspect of any instrument is not only that it is reliable and valid, but also that it is sensitive enough to discriminate between individuals. Particularly for an instrument like the K-PeCS, which is supposed to represent items that place a person at risk for MSD-UE, the ability to discriminate between those with and without MSDUE is vital. Even with a small sample, the K-PeCS demonstrated the ability to discriminate between those people with MSD-UE and those people without MSD. With a larger sample, we anticipate that more items will enter the model and lead to a more discriminative model.

To be discriminative, an instrument must have enough variability to be able to identify difference between individuals. As a secondary study, we examined the distribution of ratings for each item of the K-PeCS. The K-PeCS demonstrated good distribution on the items. Generally, for items describing static postures, such as shoulder flexion angle, or occurring/not occurring postures, such as forearm rotation or support use, the distribution of ratings tended to concentrate in one criterion. This criterion was that which was the most neutral for that item. Those items dealing with establishing the frequency of an action, such as wrist ulnar deviation angle or wrist/hand displacement, demonstrated relatively equal distributions of subjects engaging in those behaviors. For more information on K-PeCS distribution see [65].

Overall, the K-PeCS has been shown to be a reliable and valid instrument. It will be a useful tool for occupational safety personnel who work with individuals who use computers to assess their potential risk for MSD-UE and to describe their overall keyboarding style.

Conclusions

The K-PeCS will contribute to both research and intervention in the area of occupational medicine. The results of this study indicate that the K-PeCS is a reliable and valid instrument that can be use in the workplace to document the postures and behaviors of computer users. The K-PeCS can be utilized in two ways in the workplace. Due to its observational nature, and the selection and criterion of the items, any personnel who assess computer workstations to prevent injury or provide reasonable accommodation for an existing injury can use the K-PeCS to assess the workstation and develop interventions. In addition, since the K-PeCS is a highly portable and reliable tool, it will be an excellent outcome measure for research studies examining the effect of interventions in the workplace.

In this study we developed the K-PeCS an instrument that is easily used in the workplace and can provide psychometrically sound and clinically interpretable information which can be used to develop intervention strategies to reduce the postures and behaviors hypothesized to cause MSD-UE. The K-PeCS provides the ability to document the types of postural behaviors which occur prior to implementing workstation redesign. Through accurate identification of client specific problem areas, the occupational safety personnel can more efficiently and effectively implement interventions which will reduce potential risk factors. In addition occupational safety personnel can re-assess the success of their interventions by re-evaluating keyboard users' postural behaviors after the intervention has been completed. The use of a standardized observational method to ascertain and document keyboard style has the potential to improve the overall practice of office worksite intervention. In addition the K-PeCS can be used by research personnel as a method to document worksite keyboarding postures and behaviors as an outcome measure

References

1. Portney, L.G. and M.P. Watkins, *Foundations of Clinical Research.* 2008, Upper Saddle City, NJ: Pearson, Prentice Hill.
2. Gerr, F., et al., *A prospective study of computer users: I. Study design and incidence of musculoskeletal symptoms and disorders.* American Journal of Industrial Medicine, 2002. 41: p. 221-235.
3. Bureau of Labor Statistics. *Computer and internet use at work in 2001.* 2002 [cited 2002 October 30]; Available from: www.bls.qov/news.release/civaw.nrO.htm.
4. McAtamney, L. and E.N. Corlett, *RULA: A survey method for investigation of work-related upper limb disorders.* Applied Ergonomics, 1993. 24: p. 91-99.
5. Moore, J.S. and A. Garg, *The Strain Index: A proposed method to analyze jobs for risk of distal upper extremity disorders.* American Industrial Hygiene Association Journal, 1995. **56:** p. 443-458.
6. Baker, N.A. and M. Redfern, *Developing an observational instrument to evaluate personal computer keyboarding style.* Applied Ergonomics, 2005. **36:** p. 345-354.
7. Baker, N.A., J. Cook, and M. Redfern, *Rater reliability and criterion validity of the Keyboard Personal Computer Style instrument (K-PeCS).* Applied Ergonomics, in press.
8. Baker, N.A., N.B. Sussman, and *M.* Redfern, *Discriminating between individuals with and without musculoskeletal disorders of the upper extremity by means of items related to computer keyboard use.* Journal of Occupational Rehabilitation, 2008. **18:** p. 157-165.
9. Baker, N.A., et al., *Kinematics of the fingers and hands during computer keyboard use.* Clinical Biomechanics, 2007. **22:** p. 34-43.
10. Serina, E., R. Tal, and D. Rempel, *Wrist and forearm postures and motions during typing.* Ergonomics, 1999. 42: p. 938-951.
11. Simoneau, G., R. Marklin, and J. Monroe, *Wrist and forearm postures of users of conventional computer keyboards.* Human Factors, 1999. 41: p. 413-424.
12. Sommerich, C.M., W.S. Marras, and M. Parnianpour, *A quantitative description of typing biomechanics.* Journal of Occupational Rehabilitation, 1996. 6: p. 33-55.
13. Bureau of Labor Statistics (a). *Lost worktime injuries and illnesses: Characteristics and resulting time away from work, 1999.* [cited 10/08/2001]; Available from: http://www. bls. gov/news. release/osh2. nr0. htm.
14. Bureau of Labor Statistics (b). *Number of nonfatal occupational injuries and illnesses involving days away from work by part of body and selected events or exposures leading to injury or illness, 1999.* [cited 10/08/2001]; Available from: www.bls.gov/oshc d95.htm.
15. National Research Council and the Institute of Medicine, *Musculoskeletal disorders and the workplace: Low back and upper extremity,* ed. Panel on Musculoskeletal Disorders and the Workplace. Commission on Behavioral and Social Sciences Education. 2001, Washington, D.C.: National Academy Press.
16. Bureau of Labor Statistics (d). *Days away from work highest for carpal tunnel syndrome.* 2001 [cited 10/09/2001]; Available from: http://stats.bls.gov/opub/ted/2001 /apr/wkl /art0l .htm.
17. Baker, N.A., *How useful is the term 'Cumulative Trauma Disorder?'* Work, 1998. 13(2): p. 163-172.
18. Ijmker, S., et al., *Should office workers spend fewer hours at their computer? A systematic review of the literature.* Occupational and Environmental Medicine, 2007. 64(4): p. 211-222.
19. Hales, T.R., et al., *Musculoskeletal disorders among visual display terminal users in a telecommunications company.* Ergonomics, 1994. 37: p. 1603-1621.
20. Bergquist, U., et al., *Musculoskeletal disorders among visual display terminal workers: Individual, ergonomic, and work organizational factors.* Ergonomics, 1995. **38:** p. 763-776.
21. Rempel, D.M., et al., *A randomised controlled trial evaluating the effects of two workstation interventions on upper body pain and incident musculoskeletal disorders among computer operators.* Occupational and Environmental Medicine, 2006. 63(5): p. 300-6.
22. U.S. Census Bureau. *Workers using computers on the job: 1993 and 1997.* Statistical Abstract of the United States 2001 [cited 2002 February 1]; Available from: http://www.census.gov/prod/www/statistical abstract-01.html.
23. Gerr, F., C. Monteilh, and M. Marcus, *Keyboard use and musculoskeletal outcomes among computer users.* Journal of Occupational Rehabilitation, 2006. **16:** p. 265-277.

24. Armstrong, T.J., et al., *Some histological changes in carpal tunnel contents and their biomechanical implications.* Journal of Occupational Medicine, 1984. **26:** p. 197-201.
25. Goldstein, S.A., et al., *Analysis of cumulative strain in tendons and tendon sheaths.* Journal of Biomechanics, 1987. **20:** p. 1-6.
26. Marklin, R.W., G.G. Simoneau, and J.F. Monroe, *Wrist and forearm posture from typing on split and vertically inclined computer keyboards.* Human Factors, 1999. 41: p. 559-569.
27. Schuind, F., M. Ventura, and J.L. Pasteels, *Idiopathic carpal tunnel syndrome: Histologic study of flexor tendon synovium.* Journal of Hand Surgery, 1990. 15A: p. 497-503.
28. Tanzer, R.C., *The carpal- tunnel syndrome: A clinical and anatomical study.* The Journal of Bone and Joint Surgery, 1999. **41-A:** p. 626-634.
29. Rempel, D.M., et al., *Effects of static fingertip loading on carpal tunnel pressure.* Journal of Orthopedic Research, 1997. **15:** p. 422-426.
30. Werner, R., et al., *Intracarpal canal pressures: The role of finger, hand, wrist and forearm position.* Clinical Biomechanics, 1997. **12:** p. 44-51.
31. Sommerich, C.M., W.S. Marras, and M. Parnianpour, *A method for developing biomechanical profiles of hand-intensive tasks.* Clinical Biomechanics, 1998. 13: p. 261-271.
32. Rempel, D.M., et al., *Effects of forearm pronation/supination on carpal tunnel pressure.* Journal of Hand Surgery, 1998. 23A: p. 38-42.
33. Rempel, D.M., R.J. Harrison, and S. Barnhart, *Work-related cumulative trauma disorders of the upper extremity.* JAMA, 1992. 267(6): p. 838-842.
34. Psihogios, J.P., et al., *A field evaluation of monitor placement effects in VDT users.* Applied Ergonomics, 2001. **32:** p. 313-325.
35. Baker, N.A., et al., *Digit kinematics during typing with* standard *and ergonomic keyboard configurations.* International Journal of Industrial Ergonomics, 2007. 37: p. 345-355.
36. Ortiz, D.J., et al., *Measurement variability in upper extremity posture among VDT users.* Applied Ergonomics, 1997. **28:** p. 139-143.
37. Hunting, W., T. Laubli, and E. Grandjean, *Postural and visual loads* at *VDT workplaces. I. Constrained postures.* Ergonomics, 1981. 24: p. 917-931.
38. Lueder, R. *A proposed RULA for computer* users. in *Proceedings of the Ergonomics Summer Workshop.* 1996. San Francisco, CA: UC Berkeley Center for Occupational & Environmental Health Continuing Education Program.
39. Szeto, G.P., L. Straker, and S. Raine, *A field comparison of neck and shoulder postures in symptomatic and asymptomatic* office *workers.* Applied Ergonomics, 2002. 33: p. 75-84.
40. Marcus, M., et al., *A prospective study of computer* users: *11. Postural risk factors for musculoskeletal symptoms and disorders.* American Journal of Industrial Medicine, 2002. 41: p. 236-249.
41. Faucett, J. and D.M. Rempel, *VDT- related musculoskeletal symptoms: Interactions between work posture and psychosocial work factors.* American Journal of Industrial Medicine, 1994. **26:** p. 597-612.
42. Nelson, J.E., D.E. Treaster, and W.S. Marras, *Finger motion, wrist motion and tendon travel as a function of keyboard angles.* Clinical Biomechanics, 2000. **15:** p. 489-498.
43. Pascarelli, E.F. and J.J. Kella, Soft-*tissue injuries related to* use *of the computer keyboard.* Journal of Occupational Medicine, 1993. **35:** p. 522-532.
44. Rose, M.J., *Keyboard operating posture and actuation force: Implications for muscle* over-use. Applied Ergonomics, 1991. **22:** p. 198-203.
45. Feuerstein, M., et al., *Computer keyboard force and upper extremity symptoms.* Journal of Occupational and Environmental Medicine, 1997. **39:** p. 1144-1153.
46. Sommerich, C.M., et al., *Effects of notebook computer configuration and task on* user *biomechanics, productivity, and comfort.* International Journal of Industrial Ergonomics, 2002. **30:** p. 7-31.
47. Li, G. and P. Buckle, *Current techniques for* assessing *physical exposure to work-related musculoskeletal risks, with emphasis on posture-based methods.* Ergonomics, 1999. 42: p. 674-695.
48. Spielholz, P., et al., *Comparison of self-report, video observation and direct measurement methods for upper extremity musculoskeletal disorder physical risk factors.* Ergonomics, 2001. 44: p. 588-613.
49. Keyserling, W.M., et al., *A checklist for evaluating ergonomic risk* factors associated *with upper extremity cumulative trauma disorders.* Ergonomics, 1993. **36:** p. 807-831.

50. James, C.P., K.L. Harburn, and J.F. Kramer, *Cumulative trauma disorders in the upper extremities: Reliability of the Postural and Repetitive Risk-Factors Index.* Archives of Physical Medicine and Rehabilitation, 1997. **78:** p. 860-866.
51. Latko, W.A., et al., *Development and evaluation of an observational method for assessing repetition in hand tasks.* American Industrial Hygiene Association Journal, 1997. **58:** p. 278-285.
52. Colombini, *D., An observational method for classifying exposure to repetitive movements of the upper limbs.* Ergonomics, 1998. 41: p. 1261-1289.
53. Powell, C., *The Delphi techinique: myths and realities.* Journal of Advanced Nursing, 2002. 41: p. 376-382.
54. Baker, N.A. and M. Redfern. *Developing an instrument to measure keyboarding style: Obtaining content validity.* in *Human Factors and Ergonomics Society 47th Annual Meeting.* 2003. Boulder, Colorado: Human Factors and Ergonomics Society.
55. Shrout, P.E. and J.L. **Fleiss, *Intraclass correlations: Uses in assessing rater reliability.* Psychological Bulletin, 1979. 86(2):** p. 420-428.
56. Martin, B.J., et al., *Keyboard reaction force and finger flexor electomyograms during computer keyboard work.* Human Factors, 1996. **38:** p. 654-664.
57. Cook, J., et al., *Measurements of wrist and finger postures: A comparison of goniometric and motion capture techniques.* Applied Biomechanics, 2007. **23:** p. 70-78.
58. Portney, L.G. and M.P. Watkins, *Foundations of clinical research: Applications to practice.* 2nd ed. 2000, Upper Saddle River, NJ: Prentice Hall Health.
59. Sluiter, J.K., K.M. Rest, and M.H.W. Frings-Dresen, *Criteria document for evaluation the work-relatedness of upper-extremity musculoskeletal disorders.* Scandinavian Journal of Work, Environment & Health, 2001. **27(suppl** 1): p. 1-102.
60. Yassi, A., *Repetitive strain injuries.* Lancet, 1997. **349:** p. 943-947.
61. Nathan, P.A., et al., *Obesity as a risk factor for slowing of sensory conduction of the median nerve industry.* Journal of Occupational Medicine, 1992. 34(4): p. 379-383.
62. Werner, R.A., et al., *Influence of body mass index and work activity on the prevalence of median mononeuropathy at the wrist.* Occupational and Environmental Medicine, 1997. 54(4): p. 268-271.
63. Salford Systems, *CART for Windows: Users guide.* 2002, San Diego, CA: Salford Systems.
64. Wilkinson, L., *Tree structured data analysis: AID, CHAID, and CART,* in *Sawtooth/S VS TAT Joint Software Conference.* 1992: Sun Valler, ID.
65. Baker, N.A. and M. Redfern, *Postural behaviors during worksite keyboard use.* American Journal of Occupational Therapy, in press.

Publications

Peer-reviewed Journal Articles

1. **Baker** NA, Redfern M: [2005] Developing an Observational Instrument to Evaluate Personal Computer Keyboarding Style. Applied Ergonomics 36: 345-354.

This article describes the initial development of the K-PeCS instrument and relates to the overall aim of the project to develop a psychometrically valid observational instrument to measure keyboarding style.

2. **Baker** NA, Cham R, Cidboy E, Cook J, Redfern M: [2007] Kinematics of the Fingers and Hands During Computer Keyboard Use. Clinical Biomechanics 22: 34-43.

This article describes the results of a kinematics model developed to assess the concurrent-criterion validity of the K-PeCS and relates to Aim 1 of the project.

3. Cook J, **Baker** NA, Cham R, Cidboy E, Redfern M: [2007] Measurements of Wrist and Finger Postures: A Comparison of Goniometric and Motion Capture Techniques. Journal of Applied Biomechanics 23: 70-78.

This article describes the results of a method used to assess the concurrent-criterion validity of the kinematics model. Although not directly attached to an aim, it was a necessary step in developing the kinematics model.

4. **Baker** NA, Sussman N, Redfern M: [2008] Discriminating Between Individuals With and Without Musculoskeletal Disorders of the Upper Extremity by Means of Items Related to Computer Keyboard Use. Journal of Occupational Rehabilitation 18: 157-165.

This article describes the discriminate validity of the K-PeCS and relates to Aim 2 of the project.

5. **Baker** NA, Cook J, Redfern M: [in press] Rater Reliability and Concurrent Validity of The Keyboard Personal Computer Style Instrument (K-Pecs). Applied Ergonomics.

This article describes the inter-/intra-rater reliability and the concurrent validity of the K-PeCS. It relates to Aim 1 of the project

6. **Baker** NA, Redfern M: [in press] Postural behaviors during worksite keyboard use. American Journal of Occupational Therapy.

This article describes the distribution of the items on the K-PeCS and relates to the overall aim of the project to develop a psychometrically valid observational instrument to measure keyboarding style.

Peer-reviewed Conference Proceedings

1. **Baker** NA, Redfern M: [2003] Developing an instrument to measure keyboarding style: Obtaining content validity. Proc of 2003 *Human Factors and Ergonomics Society 47th Annual Meeting,* Boulder Colorado, 1164-1168, October 13-17.

This paper describes the initial development of the K-PeCS instrument and relates to the overall aim of the project to develop a psychometrically valid observational instrument to measure keyboarding style.

2. **Baker** NA, Redfern, M: [2006] Measuring computer style: The frequency and distribution of computer keyboard behaviors. Proc of the *Human Factors and Ergonomics Society 50 Annual Meeting,* San Francisco, CA, 1351-135, October 16-20.

This paper describes the distribution of the items on the K-PeCS and relates to the overall aim of the project to develop a psychometrically valid observational instrument to measure keyboarding style.

3. Baker NA, Cook J, Redfern M: [2006] The effect of gender on finger angles during keyboarding. Proc of 30 th Annual Meeting of the American Society of Biomechanics, Blacksburg, VA, September 6-9.

This paper used data obtained with the kinematics hand modeling to explore the effects of gender on keyboarding style. It demonstrates how the hand models can be used to examine keyboarding.

4. Baker NA, Redfern M: [2007] The association between computer typing style and typing speed. Proc of the *Human Factors and Ergonomics Society 51st Annual Meeting,* Baltimore, MD, 869-873, October 1-5, 2007:

This paper used data obtained using the K-PeCS to examine computer typing speed. It demonstrates the utility of the K PeCS as an outcome measure, further supporting its psychometric properties.

Principal Investigator/Program Director (Last, First, Middle): Baker, Nancy A.

Inclusion Enrollment Report

This report format should NOT be used for data collection from study participants.

Study Title: Developing an Instrument to Measure Keyboarding Style

Total Enrollment: 88 **Protocol Number: 87**

Grant Number: 5 K01 OH007826-03

PART A. TOTAL ENROLLMENT REPORT: Number of Subjects Enrolled to Date (Cumulative) by Ethnicity and Race				
	Sex/Gender			
Ethnic Category	**Females**	**Males**	**Unknown or Not Reported**	**Total**
Hispanic or Latino	2	2	0	4 **
Not Hispanic or Latino	64	17	0	81
Unknown (individuals not reporting ethnicity)	3	0	0	3
Ethnic Category: Total of All Subjects*	69	19	4	88
Racial Categories				
American Indian/Alaska Native	0	0	0	0
Asian	6	3	0	9
Native Hawaiian or Other Pacific Islander	1	0	0	1
Black or African American	6	2	0	8
White	56	14	0	70
More Than One Race	0	0	0	0
Unknown or Not Reported	0	0	0	0
Racial Categories: Total of All Subjects*	69	19	0	88

PART B. HISPANIC ENROLLMENT REPORT: Number of Hispanics or Latinos Enrolled to Date (Cumulative)				
Racial Categories	**Females**	**Males**	**Unknown or Not Reported**	**Total**
American Indian or Alaska Native	0	0	0	0
Asian	0	0	0	0
Native Hawaiian or Other Pacific Islander	0	0	0	0
Black or African American	0	0	0	0
White	2	2	0	4
More Than One Race	0	0	0	0
Unknown or Not Reported	0	0	0	0
Racial Categories: Total of Hispanics or Latinos**	2	2	0	4 **

* These totals must agree.
** These totals must agree.