Chapter 4

The Chording Glove Experiment

4.1 Introduction

This chapter describes an experiment to examine the claims set out in the previous chapter. Specifically, the Chording Glove claims to combine the quick learning time and high performance of a chord keyboard with the portability of a glove interface.

The learning rates of standard chord keyboards (see Section 2.2.3) indicate that the keymap of a chord keyboard can be learned in a short period of time. Mounting the keys on a glove should make no difference in the learning rate. As a consequence, the Chording Glove's keymap should be learned and retained in a comparable manner. In other words, we hypothesise that the 97 character keymap for the Chording Glove should be memorised to the extent that the user can perform continuous text input within 90 minutes. In addition, the keymap should remain in long term memory, allowing users to maintain their chording speed after extended periods of disuse.

After eleven hours of use, a one-handed chord keyboard can be expected to have a text entry speed around 20–24wpm. Sources differ as to the expected text entry speed of a standard keyboard. Gopher & Raij (1988) found it to be about 14wpm after 11 hours of practice , while a touch typing course claims to reach a speed of 20wpm after 12 hours of training (Noyes, 1983). However, one thing is clear, for beginner and moderate users, a one-handed chord keyboard should be as fast or faster than a QWERTY keyboard. As a consequence, we hypothesise that the Chording Glove should be able to reach input speeds of at least 20wpm after 11 hours of chording.

The expected error rate for the Chording Glove was be determined in Chapter 3 by weighting Seibel's (1962) error data against the chord's frequency of use. The result is an error rate of approximately 7%. This is, of course, the steady state error rate, ie the rate after long term use. For comparison, the error rate for the QWERTY is 12.7% (Potosnak, 1988). We hypothesise that the error rate for the Chording Glove, after 11 hours of use, should be somewhat higher than the 7% level. In addition, we hypothesise that the Chording Glove should be able to chord on any solid surface without any significant loss in speed.

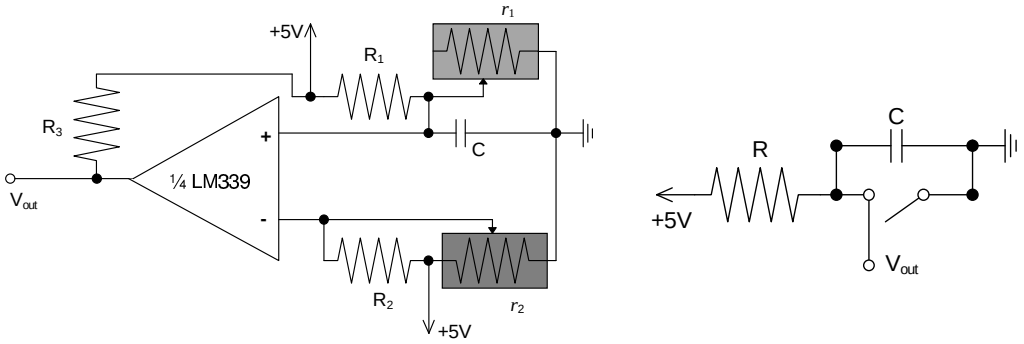
In order to test these hypotheses, a longitudinal experiment was performed. In addition, data were collected to analyse fatigue, muscle strain, preferences, and the subject's opinions on various aspects of the device in order to provide further insight into the Chording Glove's performance.

4.2 Materials

A simplified version of the Chording Glove was used to limit the scope of the experiment. It was decided that the features should be limited to only those necessary for plain, line-by-line text entry with no editing functions.

4.2.1 Shift and Function Key Changes

The <Help> key's behaviour was changed slightly for the experiment. The normal behaviour (as mentioned in Section 3.2.1) is to display the keymap when double pressed. The keymap would then disappear when <Help> is pressed again. In the experiment, the keymap is displayed while the <Help> key is depressed. When released, the keymap disappears. This is done to measure how long the subject needed to view the keymap.



(a) Resistive Foam (b) Metal Plate

Figure 4.1: Circuit diagrams for the two types of finger sensors

The <Control> shift was not needed for the experiment, nor were any of the function keys except the <Help> key. To minimise the amount of controls the subjects had to contend with, the <Control> shift was remapped in software to produce the same results as pressing the <Help> key. Since the <Help> key was now redundant and the rest of the function keys were not wanted, the entire set of function keys were removed from the glove to avoid confusion.

The LEDs next to the <Control> shift were not removed, nor were they used during the experiment.

4.2.2 Finger Sensors

The first five subjects in the experiment started out using the Resistive Foam finger sensors(Figure 4.1(a)). As the foam was compressed, the resistance (r_1) lowered. This was measured as a change in voltage. Since this was an analogue sensor, the voltage had to be compared against a set cutoff voltage. This voltage was set by a potentiometer (r_2). Each sensor had it's own control potentiometer to allow it to be adjusted to maximum sensitivity.

Once the Chording Glove was used by multiple people over a short period of time, it was found that the sensors could not handle such frequent use. The problem was that r_1 was excessively temperature dependent. The longer the sensor was in use, the more the resistance changed. Eventually the resistance would fall outside the range of r_2, making the sensor useless after just over an hour of chording.

These sensors were replaced with a new design. This was a large, non-flexible button made of two metal plates separated by springs (Fig 4.1(b)). Compressing the button touched the plates, grounding V_{out}.

In order to change the sensors without redesigning the entire circuit board, the new finger sensors were attached to where the function keys were. The software was then modified to map the function key input to the finger sensors. This could be done since the function key input expected a digital signal, as opposed to the finger sensor inputs which were designed for an analogue one. This did not cause a problem since no function keys were needed.

The new sensor design was used for the remainder of the experiments, However, as a result, the subjects who used the foam sensors suffered a degradation in performance, as compared to those who used the plate sensors. The effects of this is discussed in more detail in Section 6.1.1

4.2.3 The Keymap

Table 4.1: The reduced keymap

chord	lower case	upper case	number and math	punctuation
●○○○	a	A	5	&
●○●○	b	B	*	*
●●●○	c	C	0	%
○●●○	d	D	/	\
○○●○	e	E	3	!
●○●●	f	F		
○●●○	g	G	)	>
○●○○	h	H	2	@
○○○●	i	I	4	?
●●○●	j	J		
○●●●	k	K	^	^
○●●●	l	L	=	<
○●●○	m	M	-	_
○●○○	n	N	(	"
●○○●	o	O	7	|
○●○●	p	P	+	#
○●●○	q	Q	?	?
●●○○	r	R	9	‘
●○●○	s	S	6	$
○●○○	t	T	1	’
○●○●	u	U	[	{
○●●●	v	V		
●○○●	w	W	]	}
●○●●	x	X	*	*
●○○●	y	Y	8	~
●○●○	z	Z		
●○●●	,	,	,	;
○●●●	.	.	.	:
●○○○	space	space	space	space
○○●●	back-space	back-space	back-space	back-space
●●●●	return	return	return	return

A slightly reduced keymap was used in the experiment (Table 4.1). The special characters <`Tab`> and <`Escape`> were not shown, since they were not used in the experiment. In addition AutoCaps was turned off in the experiments as it would only add another variable to an already complex situation.

4.3 Method

4.3.1 Subject Selection

Advertisements were placed around the Queen Mary and Westfield College campus. Additional advertisements were posted on the several appropriate local internet newsgroups. Potential subjects replied by email or telephone. They were asked to fill out an initial questionnaire either on paper or via email. Adequate subjects were accepted and times were scheduled. Details on the selection criteria are available in the appendix in Section D.1.1).

Fifteen subjects were used, but 5 dropped out after the tutorial. Of the remaining 10, there were 4 males and 6 females, all right-handed and aged between 18 and 28. All the subjects described themselves as competent typists with six subjects using keyboards for only a few hours a week, and the rest typing on a daily basis. No subjects reported ever having used a chord keyboard or having experienced any RSI. Each subject was paid £1.50 per session after the tutorial, and an additional £15.00 on completing all the experiments. One subject chose not to be paid. The subjects each performed ten chording sessions following a tutorial session, spread out over a period of approximately 2–3 weeks.

4.3.2 Tutorial

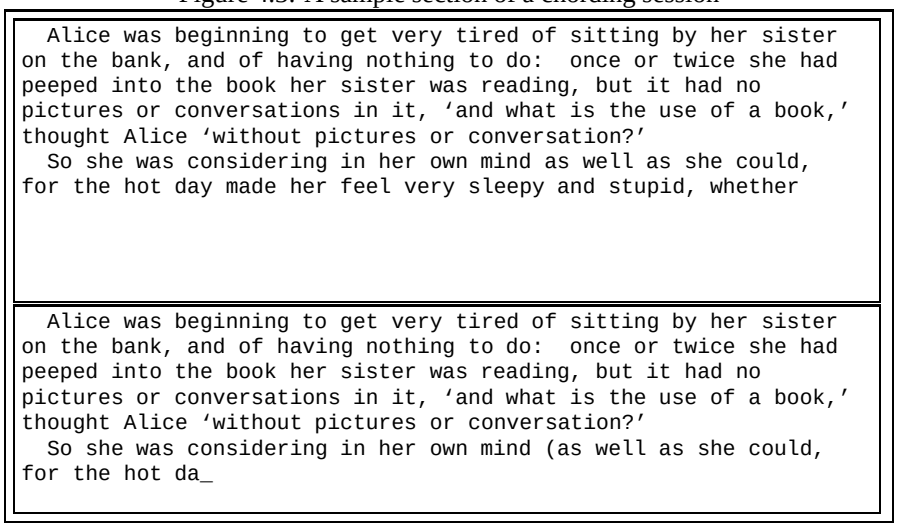
Figure 4.2: Sample text from the tutorial session. The entire tutorial is available in Appendix D

```
Type the letter g
gggg

Now type:
ing
ing

Note that 'ng' is formed by the first two fingers(index and middle)
followed by the second two fingers (middle and ring).

Type again: ing
ing

Now type:
thing
thing

this and that thing
this and that thing

let their chimney fly.
let their chi_
```

The initial session was a tutorial to teach the chord keymap. The tutorial was designed to last approximately one hour (Figure 4.2). The subject was given two sheets of paper for the tutorial. The first listed the keymap (Figure 4.1) and the second displayed the chords which are similar in shape to the characters they make (Figure 3.4). The subject learned each chord by being asked to chord a character and then generate several short phrases using it and some previously learned chords. The subjects could take as long as they needed to finish. Most took between 1 and $1\frac{1}{2}$ hours to complete. After finishing the tutorial, the subject was given a questionnaire to fill out. See Appendix D for more details on the tutorial and questionnaire.

4.3.3 Chording Sessions

Figure 4.3: A sample section of a chording session



There were ten chording sessions following the tutorial. These sessions consisted of preparation, fifty minutes of text input, and wrap-up.

Preparation

Before starting the subject is asked, *"Have you experienced any unusual or unexplained pain in your hand, arm, or back since the last session?"* The subject then puts on the glove and is asked if they are ready to begin.

Trials

The subject would then perform four chording trials. Each trial consisted of entering text which would appear on the monitor. The screen was divided into two windows. The top displayed the text, one line at a time. The subject would chord this text and their work would appear in the bottom window. When the subject pressed <Return> the next line would appear in the top window. In each session the subject was told to chord as quickly and as accurately as possible. Fixing errors was not too important, and the subjects were told to fix mistakes "only if it doesn't require too much effort".

The trial length and content were varied to avoid mental fatigue in the subject. The first and third trials were always 15 minutes long, while the second and fourth were always 10 minutes. Between each trial the subject could take a break of up to five minutes. Most subjects preferred to wait less than a minute before continuing with the trials.

The first and last trials always consisted of entering text from the novel *Alice's Adventures in Wonderland*. This was chosen because it is easy to read, but is still interesting enough to keep the subject's attention. The second and third trials alternated between text and data entry. If the first was text entry the second would be data entry, and vice versa. Each session alternated which was performed first. The data entry mostly consisted of tabular stock market data. The data was mostly numbers, but there were some words. The full text of the data entry trials is in Appendix D.

Every few sessions, during a randomly selected trial (any except the first one), the subject was asked

to chord without a chair to sit in, or without a desk to chord on. This was to test the portability of the Chording Glove. Only four of the subjects were used in these tests.

Wrap-Up

After the final trial of the day, the subject was given a questionnaire. This was the same one that was used after the tutorial (see Appendix D). The subject then was asked to schedule more sessions if they had not already done so. Afterwards the subject was given £1.50 and were done for the day. If the subject finished all ten sessions they were given a £15 bonus.

4.4 Results

4.4.1 Text Entry Speed and Error Rate

At the end of the tutorial the average overall speed was 8.9 $\pm$ 1.4wpm. The speed was calculated as the average digram time in seconds (t_d), assuming an average of 5 characters per word (MacKenzie et al., 1997). The conversion equation is:

$$speed[\text{wpm}] = \frac{12[\frac{\text{wpm}}{\text{s/char}}]}{t_d[\text{s/char}]} \tag{4.1}$$

The error rate was calculated as the ratio of errors to the total number of characters. This was 27% $\pm$ 2.5% after the tutorial. The chording speed increased over the sessions with no signs of levelling off. The chording speed at the final session was 16.8 $\pm$ 2.5 wpm. The final error rate had fallen to 17.4% $\pm$ 0.6% with some signs of levelling off (Figs 4.4 and 4.5).

4.4.2 Keymap Learning Rate

The tutorial took an average of 80 minutes to complete. By the end of the tutorial, the subjects were able to enter text while only rarely needing to view the keymap. This indicates that the chords had been learned well enough for continuous text entry. This is supported by the fact that less than 4% of the first chording session was spent looking up unremembered chords (this was the first session for which this data was available). By the 10th session the amount of time spent looking at chords had dropped to 0.4% (Figure 4.6).

One subject was asked to return 3 and 6 months later for additional chording sessions. During these periods she did not use the Chording Glove at all. The subject's final chording speed after the tenth session was 16.2wpm. After three months, at the start of the session her input speed was 13.2wpm. However, this rose to 17.0wpm within 20 minutes. Her final chording speed was nearly 5% higher than her speed at the end of her last session. The subject spent 2.8% of the time looking up chords. This increase may be due to the change from the old, resistive foam sensors to the new metal plate ones (Section 4.2.2). Regardless, it is clear her chording speed did not suffer from the absence. Three months later, at the start of the session her input speed was 13.9wpm, and rose to 17.9wpm within 30 minutes. This is 10% better than her speed at her tenth session, and 5% better than her speed at her previous trial, three months before. The subject spent 1.2% of the time looking up chords. Since the same sensors were used in both return sessions, it is clear that her performance did not decay.

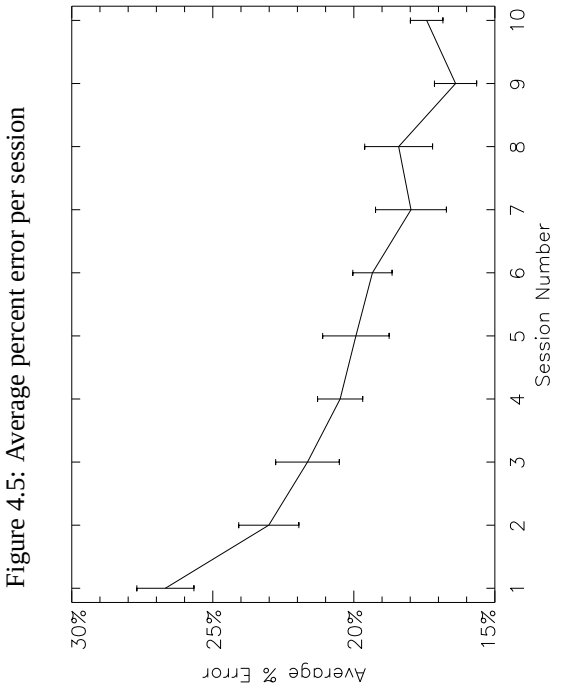


Figure 4.5: Average percent error per session

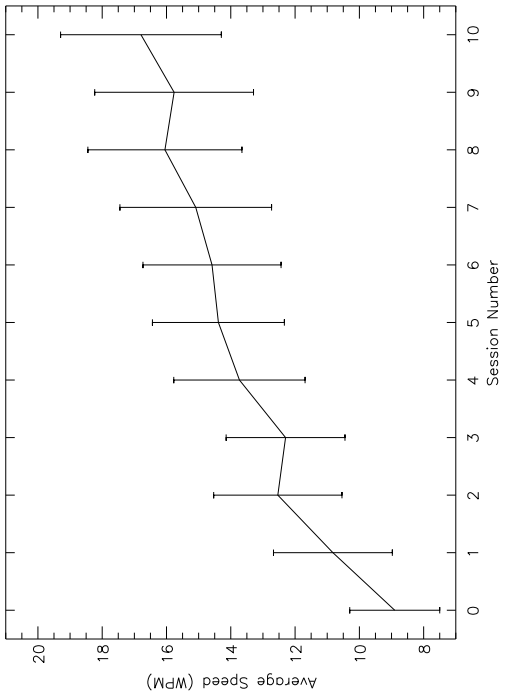


Figure 4.4: Average chording speed in WPM per session

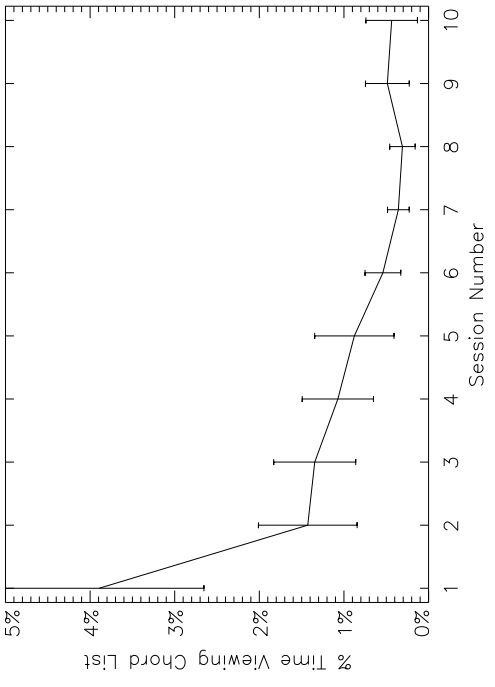


Figure 4.6: Average time spent looking up chords per session

4.4.3 Portability

To measure portability, four subjects were asked to perform a text entry trial while standing up. They were allowed to chord on any surface they wished (a desk, a file cabinet, the computer monitor, etc). The input speed of the standing-up trial was compared to the average input speed of the two other text entry trials in the same session, which were performed while sitting. The average difference in input speed was +0.47wpm $\pm$ 5.48wpm. The speed is so small compared to the standard deviation that there is really no significant difference in input speed while standing and while sitting.

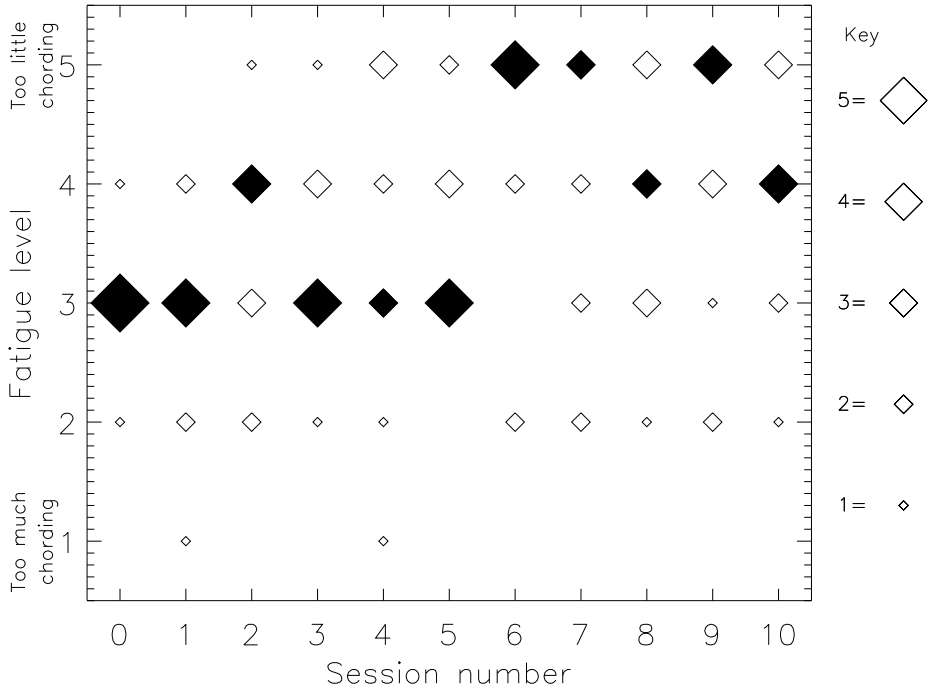
4.4.4 Questionnaire Results

The following is a summary and analysis of the subjects' responses to the daily questionnaire (Appendix C).

Fatigue

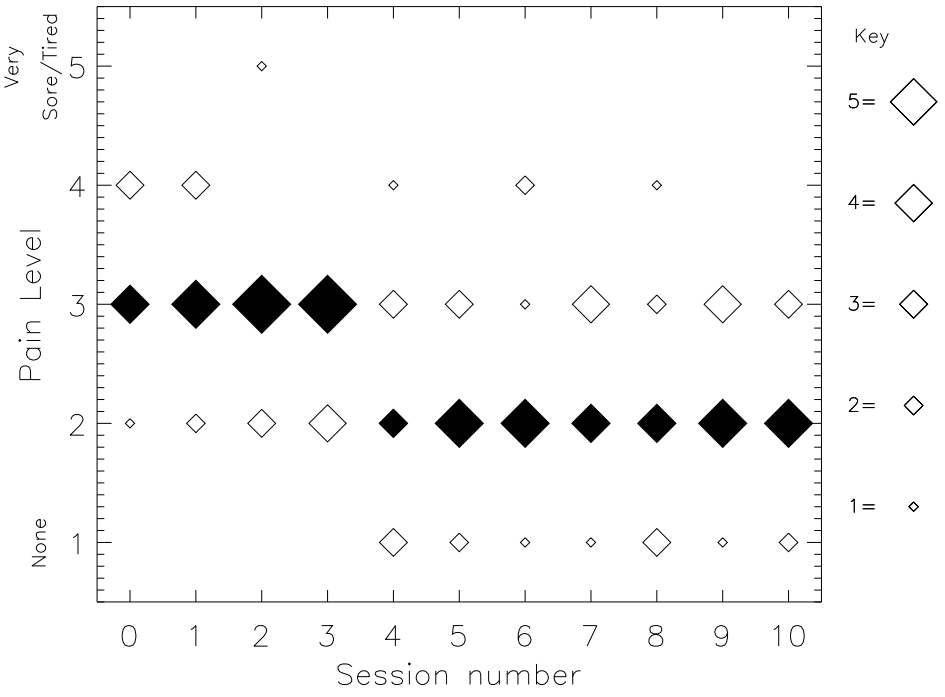
Fatigue was measured by asking the subject if they felt that they could chord for longer, had chorded too much, or if they had chorded for the right length of time. The scale was 1 to 5, where 1 was too much chording and 5 was too little. Since the fatigue levels are opinions, the scale is not necessarily linear. As a consequence computing an average value may not be meaningful. The most frequently occurring value was used instead. The mode fatigue level after the tutorial was 3 with some even distribution about that value. This corresponds to a "just about right" amount of chording. The value slowly tended upward over the sessions (corresponding to less fatigue) to the final mode value of 4 with some tendency towards 5 (Figure 4.7). A value of 4 means that they could have chorded for longer.

Figure 4.7: Distribution and mode of fatigue levels per session. The size of the glyph corresponds to the number of subjects who reported that level of fatigue. The filled glyphs are the most frequently reported fatigue level for each session.



Muscle Strain

Figure 4.8: Average muscle strain over time. The size of the glyph corresponds to the number of subjects who reported that level of fatigue. The filled glyphs are the most frequently reported fatigue level for each session



The level of muscle strain was assessed in the questionnaire given after each session. The subject was asked to rate any pain in their hand or arm on a scale of 1 to 5, where 1 was “No pain at all” and 5 was “Very sore/tired”. The initial mode pain level was 3 with a tendency towards 4. This corresponds to a bit more than “some” pain. Over the course of the first five sessions more subjects reported less levels of pain (Figure 4.8). After the fifth session, the mode pain value levelled out at 2, where it stayed for the rest of the experiments. The final pain level was 2 with a slight tendency towards 3.

Preferences

After each session the subjects were asked to compare the comfort of the Chording Glove to writing and typing. These were measured on a scale of 1 to 5, where 1 was “much worse than typing/writing” and 5 was “much better than typing/writing”. Neither of these values varied significantly over the course of the experiment. The final mode value for typing equally was distributed between 2 and 3, which means the subjects found it as good as or slightly worse than typing. The final mode value for writing was 2 with slightly more tendency towards 3 than 1. This means the subjects preferred writing over chording, but not by much.

The subject were also asked if they would want the Chording Glove for personal use. The scale for this was 1 to 5, where 1 was “Never!” and 5 was “Definitely”. There was no significant change in the responses over the duration of the experiment. The final mode value was 3 with most of the rest of the subjects reporting 2, this corresponds to being somewhat less than “sometimes”.

Opinions

Table 4.2: Top 5 positive and negative comments about the Chording Glove

	Likes		Dislikes	
	comment	*number*	*comment*	*number*
1	One handed use	5	Some chords hard to make	5
2	Visual supervision	5	Chording is too slow	5
3	Mnemonics/memorisation	3	General hardware problems	5
4	Portability	2	Straining to use	4
5	Similar to piano	2	Difficult to memorise	2

Table 4.2 shows the top five most common positive and negative comments made by the subjects over the duration of the experiment and the number of subjects who made those comments. The most preferred aspects of the glove were the one handed use and the lack of visual supervision in chording. The least preferred aspects were almost all due, at least in part, to the low sensitivity of the finger sensors (both old and new). The insensitive sensors made the chords which used more fingers more difficult to create. This slowed down the chording speeds and added to the muscle strain.

4.4.5 Analysis of Questionnaire Data and Final Results

Table 4.3 tabulates the results of the initial questionnaire, the experimental data, and the final daily questionnaire. The meaning of each column is described below.

Personal data Twelve questions were asked on the initial questionnaire (Section D.1.1). Three questions were answered the same by all subjects: All subjects were right-handed with no previous RSI or chord keyboard experience. The nine remaining questions are described below:

Subject This is a unique random number assigned to the subject.

Language This is the subject's native language.

Sex Male or female.

Glasses Does the subject wear glasses? Yes or no. All but two of the subjects wore glasses, making this variable unusable in a statistical analysis.

Music This is a rating of 0 to 5 of how well the subject can play a musical instrument. If the subject can play more than one, the highest rating is used. Zero corresponds to no knowlegde and 5 correponds to proficient.

Sign This is a rating of 0 to 5 of how well the subject knows any sign language. Zero is no knowledge and 5 is fluent.

Usage This is a rating of 0 to 5 of how well the subject can type on a keyboard. Zero is "never used one" and 5 is "very good at touch typing".

Table 4.3: Experimental data for each subject

Subject	Personal data								Experimental Data					Opinion data				
	Language	Sex	Glasses	Music	Sign	Usage	QWERTY	Frequency	Speed	Error	Help	Tutorial	Portability	Pain	Fatigue	Typing	Writing	Use
1	English	Male	Yes	5	0	4	60	4	19.3±11.7	20.6±2.0	0.99±1.48	112.1	—	3	4	2	3	3
2	English	Female	Yes	3	2	4	55	3	12.0±4.4	18.2±1.4	0.15±0.30	44.2	—	2	4	2	2	3
3	English	Female	Yes	0	1	4	18	3	21.7±8.4	14.3±2.6	0.04±0.03	77.7	+1.2±14.4	3	3	3	2	3
4	Spanish	Male	Yes	0	2	3	40	5	19.7±6.4	16.7±2.2	0.00±0.00	76.4	-0.74±7.87	1	5	3	2	4
5	English	Female	Yes	5	0	3	27	4	20.6±10.3	18.8±0.8	0.01±0.01	50.3	+1.4±11.4	3	2	2	2	4
6	Spanish	Female	Yes	3	4	3	30	3	16.4±8.1	9.3±1.4	0.00±0.00	77.5	—	2	4	2	1	4
7	English	Male	No	2	1	4	30	2	10.2±4.5	18.3±1.8	2.41±2.49	89.7	—	2	4	3	3	4
8	French	Female	No	4	0	4	40	4	16.2±6.8	27.7±2.9	0.48±0.64	120.0	—	2	5	3	2	3
9	French	Female	Yes	0	0	3	8	3	15.7±8.1	9.8±0.2	0.00±0.00	87.4	+0.01±8.96	1	5	2	1	3
10	English	Male	Yes	3	0	3	40	2	16.1±7.2	20.4±1.5	0.30±0.59	63.0	—	2	3	3	3	3

QWERTY This is the subject's self-reported typing speed in words per minute on a QWERTY keyboard. The validity of this is questionable, since it was not tested.

Frequency This is a rating of 0 to 5 of how often the subject uses a keyboard. Zero is "never" and 5 is "several hours per day".

Experimental data These are the final values for each person of the data collected in the experiment.

Speed This is the subject's average speed on the Chording Glove during their last session, measured in words per minute.

Error This is the subject's final ratio of incorrect characters to total characters.

Help This is the subject's final percent time spent looking up chords.

Tutorial This is how long (in minutes) the subject took to complete the tutorial.

Portability This is the change in the subject's chording speed between sitting down at a desk and standing up, in words per minute. A negative number indicates that they chorded faster when standing.

Opinion data These are the final values each person gave for the daily questionnaire (Section D.1.2.

Pain This is the subject's final reported pain level after using the Chording Glove for an hour. This is on a scale of 1 to 5 where 1 is "no pain at all" and 5 is "very sore/tired".

Fatigue This the final value of how tired the subject was reported to be after chording for an hour. This is on a scale of 1 to 5 where 1 is "too much chording" and 5 is "could chord for longer".

Typing This is the final reported value for the Chording Glove's comfort relative to typing. This is on a scale of 1 to 5 where 1 was "much worse than typing" and 5 was "much better than typing". This value did not change significantly over the course of the experiment.

Writing This is the final reported value for the Chording Glove's comfort relative to writing. This is on a scale of 1 to 5 where 1 was "much worse than writing" and 5 was "much better than writing". This value did not change significantly over the course of the experiment.

Use This is the final value for the subject's opinion if they would want the Chording Glove for personal use.This was on a scale of 1 to 5, where 1 was "Never!" and 5 was "Definitely". This value did not change significantly over the course of the experiment.

Table 4.4: Correlations of Personal, Experimental, and Opinion data. The value given is the square of the correlation coefficient. Values in **bold** are significantly different from zero at the 5% level. $n = 10$ for all calculations except for the following: † Subjects who had no musial experience were not used in this calculation ($n = 7$). ‡ Subjects who did not know any sign language were not used in this calculation ($n = 5$). § Only the subjects who took part in the portability tests were used in this calculation ($n = 4$).

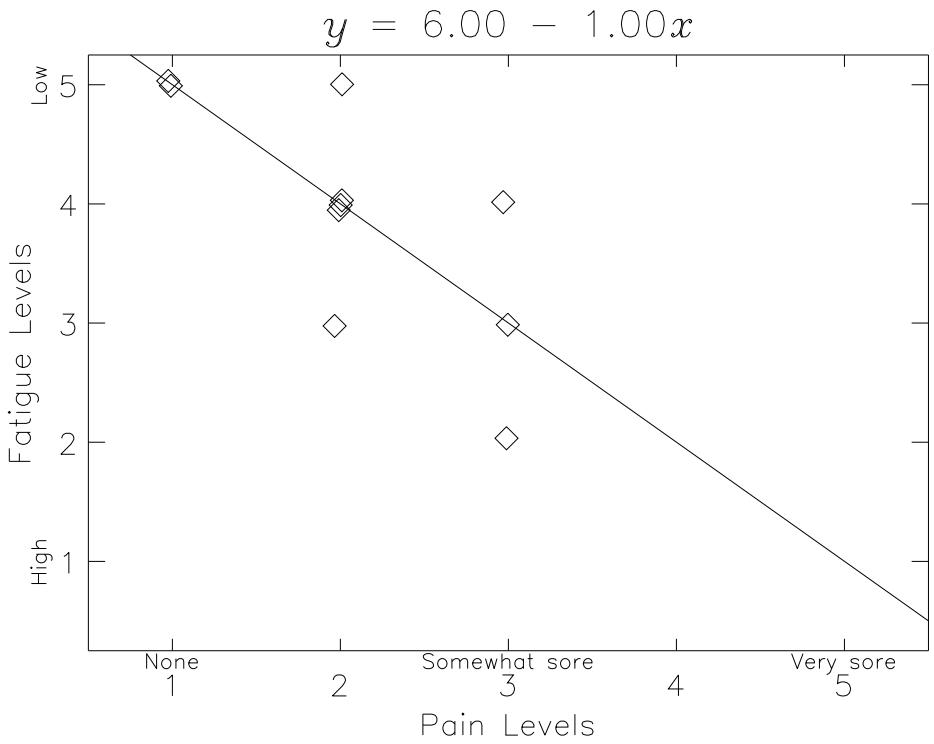
	Speed	Error	Help	Tutorial	Port.	Pain	Fatigue	Typing	Writing	Use
Music	**0.80**†	0.31	0.17†	0.005	0.38§	0.74†	0.14	0.14	0.12	0.139†
Sign	0.025	0.58‡	0.22‡	0.075	0.34 §	0.083‡	0.083‡	0.56‡	0.75‡	0.23
Usage	0.065	0.22	0.27	0.15	0.23§	0.18	0.011	0.040	0.18	0.17
QWERTY	0.020	0.33	0.033	0.005	0.11§	0.045	0.006	0.007	0.30	0.028
Frequency	0.36	0.043	0.15	0.043	0.26§	0.002	0.073	0.012	0.043	0.033
Speed	1.0	0.003	0.32	0.002	0.27§	0.15	0.10	0.000	0.018	0.000
Error	0.003	1.0	0.090	0.10	0.080§	0.075	0.000	0.17	**0.41**	0.067
Help	0.32	0.090	1.0	0.39	0.36§	0.014	0.007	0.083	**0.41**	0.036
Tutorial	0.002	0.10	0.39	1.0	0.35§	0.001	0.32	0.058	0.016	0.051
Portability	0.27§	0.080§	0.36§	0.35§	1.0§	0.90§	0.88§	0.074§	0.091§	0.025§
Pain	0.15	0.075	0.014	0.001	0.90§	1.0	**0.55**	0.20	0.15	0.014
Fatigue	0.10	0.000	0.007	0.32	0.88§	**0.55**	1.0	0.011	0.083	0.017
Typing	0.000	0.17	0.083	0.058	0.074§	0.020	0.011	1.0	0.18	0.000
Writing	0.018	**0.41**	**0.41**	0.016	0.091§	0.15	0.083	0.18	1.0	0.014
Use	0.000	0.067	0.036	0.051	0.025§	0.014	0.017	0.000	0.014	1.0

Relationships A series of regression analyses were performed on the data. Language, Sex and Glasses were left out of the analysis because they are categorical variables not suited to such an analysis. A table was generated of the correlations of all the variable. Personal data were not correlated against each other because any significance would tell nothing about the Chording Glove. Table 4.4 lists the squares of the correlation coefficients (r^2) for each of the variables. Bold numbers are significant at the 5% level. The details of the correlations significant at the 5% level are show in Table 4.5 and the results are analysed below.

Table 4.5: Summary of significant correlations

x	y	n	slope	S_e	r^2	T	p
Pain (explanitory)	**Fatigue** (explanitory)	10	-1.00	0.32	0.55	-3.13	<0.02
Music (explanitory)	**Speed** (dependent)	7	2.93	0.65	0.80	4.54	<0.05
Writing (explanitory)	**Error** (dependent)	10	4.66	0.28	0.41	2.34	<0.05
Writing (explanitory)	**Help** (dependent)	10	0.66	2.00	0.41	2.34	<0.05

Figure 4.9: Muscle Strain vs. Fatigue. For additional clarity, duplicate points are slightly offset.



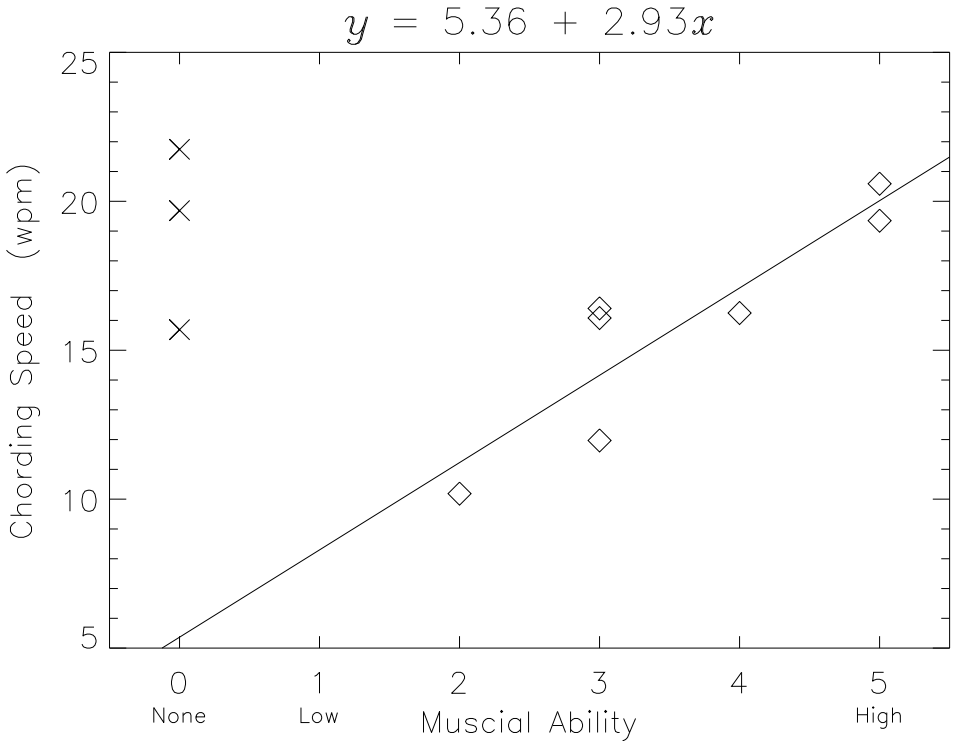
Muscle Strain and Fatigue The regression analysis gives a greater than 98% likelihood of a negative linear correlation between the levels of pain and fatigue (r^2=0.55) (Figure 4.9). The high degree of correlation is not unexpected. It states that those subjects who were uncomfortable chording became tired faster. The experimental results agree with what we would intuitively expect.

Chording Speed and Musical ability There appears to be a linear relationship between musical ability and chording speed. The greater the person's self-reported musical ability, the faster their final input speed (Figure 4.10). The correlation coefficient squared (r^2) is 0.80, which is significant at the 5% level. However this relationship only holds when those who do not play any instruments are weighted out of the calculations. When these people are included r^2 drops to 0.00.

The people who gave zero for an answer are those who do not play any instruments. One interpretation of these results is that practicing a musical instrument can help with the independent finger coordination needed for chording. However, this is obviously not the only way to achieve proficiency, as some of the non-musical people had fairly high chording speeds.

Writing preferences There was a positive correlation between the error rate and preference to writing significant at the 5% level (r^2=0.41). There was also a positive correlation between the help use and preference to writing which is significant to the same level at 5% (r^2=0.41). The relationship is counter-intuitive. It states that those who remembered the keymap less or made more mistakes preferred to use the Chording Glove, rather than write. There was not very much variation in writing preferences, as it ranged from 1 to 3, on a scale of 1–5. Half of the values were clustered at 2, while two were at 1 and three values were at 3 (Figures 4.11(a) and 4.11(b)) . Considering the poor distribution of values and the

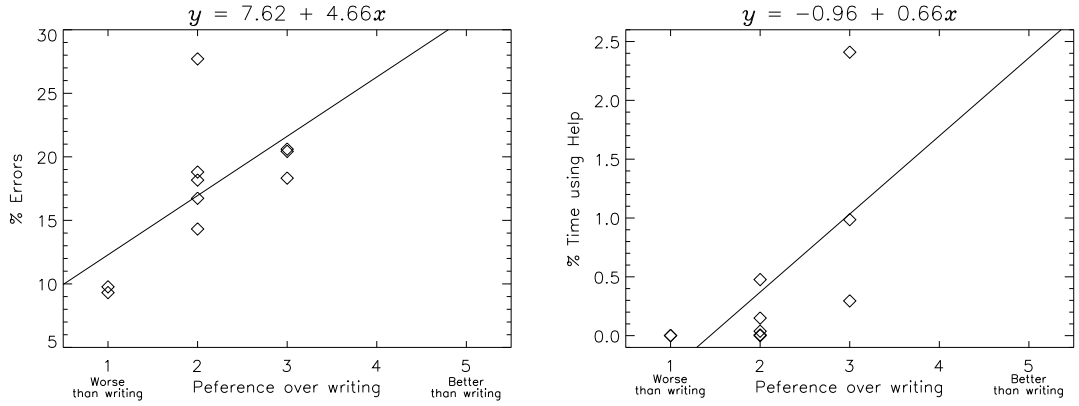
Figure 4.10: Chording speed vs. Musical ability. Diamonds ($\diamond$) are used for the people who know a sign language and are used in the regression. $\times$ is used to mark those who do not know any sign languages and are not used in the regression.



realtively low r^2 values, it is likely this relationship is coincidence.

4.5 Discussion

The subjects took an average of 80 minutes to learn the entire chord set well enough to allow continuous text entry. Most chord keymaps claim to take between 30 to 60 minutes to memorise (Gopher & Raij,



(a) Writing preferences vs. error rate

(b) Writing preferences vs. help use

Figure 4.11: Correlations of writing preferences

1988; Kirschenbaum et al., 1986; Microsoft Corporation, 1995; Roberts, 1995). The time for memorisation for this keymap is slightly longer because the character set is much larger, containing all the characters from a standard keyboard. Most other chord keymaps use only the letters when measuring the time taken to memorise the keymap. Since just under half the tutorial is spent with numbers and punctuation, a rough estimate would put the time to learn just the letters at 40–45 minutes. This falls right in the middle of the standard 30–60 minute range.

The evidence suggests that it is faster to learn touch typing on this chording system than on a standard keyboard. After about an hour the subjects could chord without constantly looking at a guide. After 6 hours the learning curve levelled off, with subjects needing to look up a few seldom used chords. Touch typists often require visual supervision long after the keyboard layout has been memorised. Many casual typists are never able to type without visual supervision (Gopher & Raij, 1988).

The data also suggests that the keymap goes into long term memory within ten sessions. While only one subject was used to determine the long term effects, the results implied that a user returning to the Chording Glove after a long absence can quickly recall the keymap. In addition, the fact that the subject's performance improved both times she returned from an absence implies that the coordination skills are retained as well. To give a fuller understanding of the effects of long-term disuse, this experiment needs to be extended to include more users and testing over a longer period of time.

The above implications agree with the hypothesis that the learning and remembering the keymap for Chording Glove is no more difficult than for a normal chord keyboard. This further suggests that the keymap designed for the Chording Glove is as good as existing keymaps for chord keyboards.

After 11 hours of training the average input speed for the Chording Glove was 16.8 wpm. This is less than the expected value of 20wpm. However, this is higher than Gopher & Raij's (1988) value of 14wpm for the QWERTY. The slower input speed of the Chording Glove is due to the low quality finger sensors used in the experiment. They were not sensitive enough for general text input. In addition these sensors were also too large to allow comfortable freedom of movement. Smaller, more accurate sensors should increase the text input speed significantly. The steady state expected error rate is about 7%. We would expect the error rate after 11 hours to be slightly higher. The Chording Glove's experimentally determined error rate after 11 hours is 17.4%, which is more than twice the expected value. The inflated error rate can be explained by the low accuracy of the sensors which often caused problems with chords which used most of the fingers. Again, more accurate sensors should reduce the error rate to a more comparable level.

There was no significant difference in the subjects' speed when chording while standing or sitting. In addition, one-handed use, lack of visual supervision, and portability were three of the top four most-liked attributes of the Chording Glove. All of these imply that the Chording Glove has potential for an unobtrusive input device in a mobile environment.

Most subjects reported feeling some pain in their hand when they first used the glove. This occurred for the first few sessions. By the last session, the subjects claimed to feel some pain immediately after chording, but this quickly diminished. The reported pain level slowly decreased over the course of the experiment, implying that the discomfort they felt was temporary and would eventually disappear as they

became acclimated to the glove. This is reinforced by the fact that, as the subjects performed more experiments, they felt more and more willing to chord for longer periods. None of the subjects reported pain in their upper arms or back during the course of the experiment, only the hand. However, as each session was only an hour long, there is no data as to the effects of prolonged use of the Chording Glove. This needs to be addressed in further experimentation.

The muscle strain and fatigue that the subjects felt lessened as they used the Chording Glove more, however the final values were still higher than desired. This is unexpected because research has shown that a chord keyboard should cause less exertion than a standard one (Kirschenbaum et al., 1986). Like error rate and input speed, it its likely that the extra strain was due to the low-sensitivity of the finger sensors, which required more pressure to trigger than they should have. Smaller sensors would allow the users to chord in more comfortable positions, reducing strain. Lowering the noise and increasing the sensitivity of the sensors should reduce the amount of work in chording, reducing fatigue.