EXPLORING HUMAN COMPUTER INTERACTION AND ITS IMPLICATIONS ON MODELING FOR INDIVIDUALS WITH DISABILITIES

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Computers provide an interface to the world for many individuals with disabilities and without effective computer access, quality of life may be severely diminished. As a result of this dependence, optimal human computer interaction (HCI) between a user and their computer is of paramount importance. Optimal HCI for individuals with disabilities relies on both the existence of products which provide the desired functionality and the selection of appropriate products and training methods for a given individual. From a product availability standpoint, optimal HCI often depends on modeling techniques used during the development process to evaluate a design, assess usability and predict performance. Computer access evaluations are often too brief in duration and depend on the products present at the site of the evaluation. Models could assist clinicians in dealing with the problems of limited time with clients, limited products for the client to trial, and the seemingly unlimited system configurations available with many potential solutions. Current HCI modeling techniques have been developed and applied to the performance of able-bodied individuals. Research concerning modeling performance for individuals with disabilities has been limited. This study explores HCI as it applies to both able-bodied and individuals with disabilities. Eleven participants (5 able-bodied / 6 with disabilities) were recruited and asked to transcribe sentences presented by a text entry interface supporting word prediction with the use of an on-screen keyboard while time stamped keystroke and eye fixation data was collected. Data was examined to identify sequences of behavior, performance

changes based on experience, and performance differences between able-bodied and participants with disabilities. The feasibility of creating models based on the collected data was explored. A modeling technique must support selection from multiple sequences of behavior to perform a particular type of action and variation in execution time for primitive operations in addition to handling errors. The primary contributions made by this study were knowledge gained relative to the design of the test bench and experimental protocol.

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PREFACE

This work is dedicated to the memory of my mother.

Diane Marie Smith
1944 – 2007

She fought the good fight, she finished the race, and she kept the faith.

Table 1. Acronyms and abbreviations

AB	able-bodied participants
AT	assistive technology
CP	Cerebral Palsy
DQW	ISCAN Raw Eye Movement Data Acquisition Software
FIX	keystroke event to fix an error - backspace
GOMS	goals, operators, methods and selection rules
HCI	human computer interaction
HIP	human information processing
I	input stream
IRB	institutional review board
IT	information technology
KLM	keystroke level model
KN	fixation on keyboard followed by a keystroke (single fixation)
KO	fixation on keyboard followed by a fixation outside the area of interest
KP	fixation on keyboard followed by a fixation on the presented text
KT	fixation on keyboard followed by a fixation on the transcribed text
KW	fixation on keyboard followed by a fixation on the word prediction list
LETTER	keystroke event to enter an alphabetical character
LO	letters only typing condition
MHP	model human processor
OK	fixation outside the area of interest followed by a fixation on the keyboard
ON	fixation outside the area of interest followed by a keystroke (single fixation)
OP	fixation outside the area of interest followed by a fixation on the presented text
OT	fixation outside the area of interest followed by a fixation on the transcribed text
OW	fixation outside the area of interest followed by a fixation on the word prediction list
P1	participant 1
P2	participant 2
P3	participant 3
P4	participant 4
P5	participant 5
P6	participant 6
PK	fixation on presented text followed by a fixation on the keyboard
PN	fixation on presented text followed by a keystroke (single fixation)
PO	fixation on presented text followed by a fixation outside the area of interest
PRZ	ISCAN Point of Regard Data Analysis Software
PT	fixation on presented text followed by a fixation on the transcribed text
PW	fixation on presented text followed by a fixation on the word prediction list
T	transcribed text
TER	text entry rate
TK	fixation on transcribed text followed by a fixation on the keyboard

TN	fixation on transcribed text followed by a keystroke (single fixation)
TO	fixation on transcribed text followed by a fixation outside the area of interest
TP	fixation on transcribed text followed by a fixation on the presented text
TRANSITION	transition keystroke event – enter key
TW	fixation on transcribed text followed by a fixation on the word prediction list
SCI	spinal cord injury
SPACE	space keystroke event – space key
WK	fixation on the word prediction list followed by a fixation on the keyboard
WN	fixation on the word prediction list followed by a keystroke (single fixation)
WO	fixation on the word prediction list followed by a fixation outside the area of interest
WP	fixation on the word prediction list followed by a fixation on the presented text
WP	word prediction typing condition
WPSELECTION	word prediction selection keystroke event – numeric character
WT	fixation on the word prediction list followed by a fixation on the transcribed text

1.0 INTRODUCTION

Computers are a vital component in the lives of many people today, yet their potential to revolutionize the lives of others remains untapped. A variety of factors such as limited income, physical impairments, and a fear of technology all contribute to the Digital Divide. Statistics based on the Computer and Internet Use supplement to the Current Population Survey from 1998 show that people with disabilities are less than half as likely to have access to computers at home and less than one third as likely to have Internet access at home than non-disabled individuals (1). An analysis based on the Computer and Internet Use Supplement to the Current Population Survey from 2003 shows that while over half of the able-bodied respondents use a computer at home less than one third of the individuals with disabilities do so (2). Controlling for the presence of a computer in the home shows that individuals with disabilities are 10% less likely to use the computer than able bodied individuals suggesting the presence of a Disability Divide.

Computer access can be a gateway to the world, providing a vast array of services including communication with family and friends, employment, education, banking, paying bills and shopping. This is all in addition to providing the ability to access an unlimited amount of information related to virtually any topic imaginable. Dobransky and Hargittai (2) provide an extensive review of studies examining disability and access to IT (information technology). Identified benefits of access to IT are both psychological and physical with increases found in self esteem, independence and health related outcomes. Identified barriers to IT access include cost, support, and assistive technology in regards to availability and performance.

While programs are being initiated to provide computers and basic computer literacy training to individuals with disabilities (3), accessibility issues related to assistive technology remain a barrier. Availability, appropriate selection, cost, and training all provide challenges for individuals needing assistive technology. Many individuals using assistive technology for computer access are left fatigued and frustrated.

Computers provide an interface to the world for many individuals with disabilities and without effective access, quality of life may be severely diminished. As a result of this dependence, optimal human computer interaction (HCI) between a user and their computer is of paramount importance. Optimal HCI for individuals with disabilities is dependent on both the existence of products which support or augment the individual's abilities and the selection of appropriate products for that individual.

1.1 PRODUCT DEVELOPMENT

From a product availability standpoint, optimal HCI often depends on modeling techniques used during the development process to evaluate a design, assess usability and predict performance. Unfortunately, current HCI models are calibrated exclusively on able-bodied individuals and the effect of disability on these models is neither understood nor considered (4, 5).

Assistive technology (AT) is applied to computer access with the intention of compensating for physical limitations experienced by the user. Solutions allow the user to interact with the system but they are often less than ideal and may not fully exploit the capabilities of the individual due to a general lack of knowledge of HCI as it relates to disabled persons.

Additionally, while Section 508 of the Rehabilitation Act mandates equal access to electronic and information technologies for government employees and recipients of government funds, accordance and enforcement of the law are problematic due to incomplete guidelines (6). AT is typically applied to provide access to existing products developed for able-bodied users; as a result, disabled users will often be limited to some extent by the original product design. AT is often developed or modified in response to the release of products developed for an able bodied user group, creating a lag between the availability of new products and the required AT support (2). This creates a cycle in which AT support is always a step behind development of mainstream products. Development of HCI models that apply to disabled users will assist in the creation of requirements specifications for products that are truly accessible.

1.2 COMPUTER ACCESS EVALUATIONS

Initial assessments of clients for assistive technology to support computer access are often too brief in duration with little to no follow up to assess performance after the client has become accustomed to using the technology (7). Additionally, the assessment often relies heavily on the experience of the clinician with qualitative input from the client. This input from the client, while a critical component of the assessment process, will typically reflect ease of first use for the technology, which may differ significantly from effective long-term use (8).

Effective performance must be defined as it relates to a given client’s goals and abilities. Often optimization of the time required to complete a task is sufficient to maximize performance however in some cases performance is strongly influenced by the onset of fatigue. In this situation minimizing motor requirements (keystrokes, mouse clicks, switch activations, etc.) assumes greater importance. The goal of performance measurement and prediction is to identify solutions that will support sustained, optimal usability for an individual client with their system.

Software developers use HCI modeling techniques to predict user interaction with systems in various stages of development in order to optimize performance. These predictions may include specification of the methods a user will select and the corresponding execution time to complete a specified task. It is postulated that a similar approach can be used to develop models for computer access assessment in clinical practice. Techniques are required to support prediction of user performance under varying conditions ranging from novice use, in which the user is learning the system features, to a level of expertise often characterized by automaticity of motor response. Performance predictions should also consider variations in physical condition, the effect of multiple conditions, and the effects of user fatigue. Ideally quantitative measures of specific functions would be obtained as part of the assessment process and then inserted into empirically validated models to provide predictions of future performance under a variety of conditions.

2.0 BACKGROUND

2.1 HCI MODELING

Models are used to provide approximations of system behavior, most often prior to availability of the complete system. In this way, they allow designers to experiment with different options without requiring a prototype and subsequent testing of each concept. Models can range in detail and complexity from engineering models which use mathematical expressions to predict performance to descriptive models which provide a framework for designers to describe and think about problems (9). The strength of using models lies in the ability they give designers to explore the design space while minimizing time and cost.

2.1.1 MHP (Model Human Processor)

The model human processor (MHP), introduced by Card, Moran, and Newell (10), is one of the most widely recognized human information processing (HIP) models ever developed (11). MHP is a simplistic engineering HIP model that supports prediction of processing sequences and durations relatively accurately for able-bodied individuals based on established normal ranges of values.

MHP is based on the notion that a human can be modeled as a computer system consisting of perceptual, cognitive and motor processors with working and long term memory storage (10). These processors are assumed to function in series and principles of operation are provided that describe performance.

For a given task, cognitive psychology provides the basis for predicting the number and sequence of cycles executed by each processor. Additionally, typical ranges for the perceptual, cognitive and motor cycle times have been established for the able-bodied population (10, 12). Combining this information allows fairly accurate prediction of the sequence of processing cycles and the total response time for a given stimulus for able-bodied individuals.

Unfortunately due to the level of granularity required, use of the MHP can be quite labor intensive for all but the simplest of tasks making it impractical for modeling real world applications.

2.1.2 GOMS (Goals, Operators, Methods, and Selection rules)

In order to successfully model human computer interaction one must understand both the application or system being used and the anticipated manner in which the user will interact with the system to achieve the desired goals. One of the most widely used families of models within HCI is GOMS. The basic premise driving the GOMS models as described by Card, Moran, and Newell (10) is a general description of human interaction with the world at large. When humans decide to accomplish something, they establish a goal, perform some sequence of actions to achieve the goal and evaluate the result (8). GOMS is based on identification of *goals* to achieve, *operators* (primitive actions performed by the user), *methods* (sequences of operators) and *selection rules* (determine which methods should be applied when multiple options are available). There are a variety of GOMS modeling techniques available to designers; John and Kieras (13) provide guidelines for selection of the most appropriate technique to use based on the design situation. The GOMS models are widely accepted in the HCI community and have been validated in a plethora of diverse real world applications (11).

2.2 PREVIOUS RESEARCH

2.2.1 MHP

Efforts to use established MHP models to predict performance of disabled individuals have been somewhat inconclusive due to limited sample sizes, the information available from the data collected, and lack of statistical analysis. These preliminary studies have found an increase in perceptual and cognitive cycle times in addition to discrepancies in motor processing performance (5, 14). As expected, motor performance varied significantly depending on the degree of motion impairment experienced by the participant. For severely motion-impaired participants it appeared that additional perceptual and/or cognitive processing cycles were inserted throughout motor processing. Conclusive sequences of the processing cycles could not be determined based on the data captured.

Researchers speculated that additional workload was placed on these participants due to the effort required to control physical movement. The source of the unanticipated perceptual and/or cognitive cycles may have been the need to process feedback concerning the movement and to make frequent adjustments (5, 14). A thorough examination of the mental workload related to motor processing is called for in order to understand the effect of motor impairment on MHP models.

2.2.2 GOMS

Koester and Levine (15-19) have done extensive work creating and validating keystroke level GOMS models for performance with word prediction systems. An unanticipated conclusion drawn from their analysis was that use of word prediction does not necessarily improve text entry rate (15). In some cases keystroke savings does not balance out the increased cognitive and perceptual load induced when using word prediction. The mental cost of using word prediction was apparent in data collected for both able-bodied and disabled participants but was most prominent in data from participants with spinal cord injury (SCI) (17). Key press time increased by almost 50% for these participants when word prediction was used. Accuracy of a priori predictions for word entry times was good with an error of 20% for able-bodied participants and 35% for participants with SCI (18). However generalizability of these results is questionable due to the conditions under which the models were created and tested. Participants were asked to follow specific strategies when using word prediction, data including errors was discarded, recruitment of participants with disabilities was limited to those with SCI, and the number of test sessions may not have provided enough practice for learning purposes. Building on their previous work Koester and Levine (19) created and simulated models examining the effect of different system configurations and user strategies with word prediction systems in order to show the clinical applications of model simulations. Overall, their work provides an excellent example of the benefits which can be incurred through modeling and simulation in both design and clinical assessment.

2.3 MOTIVATION

Research concerning modeling performance for individuals with disabilities has been extremely limited. Models which are applicable to individuals with disabilities are essential for both product development and clinical practice. Universal design will never be achieved until individuals with disabilities are included as part of the target user group during product specification and development. Given the difficulties recruiting these individuals for user testing, modeling is a primary option available to achieve the required accessibility. Beyond universal design is the need for developers of AT to understand the abilities and limitations of their target user group. The diversity of disabilities and compounding issues of multiple disabilities result in a wide expanse of functionality. Collection of functional and performance measurements from individuals with disabilities would provide useful information for AT developers. This functional data could be managed and dispersed similar to anthropometric data.

Additionally, models of performance which are applicable to individuals with disabilities can serve to expand the options available to clinicians performing computer access assessments. Tools such as Compass (20) and EvaluWare are helpful in providing comparisons of performance when clients are able to try different products, thus depending on time and product availability during an assessment. There is a need for quantitative methods of determining the appropriate match between assistive technology and clients which do not rely on the client testing a large number of products and configurations. The ability to model interaction between a product and a client could be used to determine if there is a potential fit between the two and if so, to appropriately configure the system for the client. Clinicians could determine if a given product should be requested for trial when the product is not available in the clinic or present at the site of the evaluation. Models could assist clinicians in dealing with the problems of limited time with clients, limited products for the client to try, and the seemingly unlimited system configurations available with many potential solutions. With this assistance the computer access assessment process could provide more effective long term solutions for individuals.

3.0 RESEARCH QUESTIONS

Eleven participants were recruited and asked to transcribe sentences using an on-screen keyboard while time-stamped keystroke and eye fixation data was collected. Visual fixations on identified areas of interest and keystrokes were categorized individually as events. A sequences of events consisted of one or more visual fixations followed by a keystroke. Each sequence of events was categorized based on the type of keystroke that terminated the sequence. Keystroke types included error correction, word prediction selection, alphabetical character, space and enter. The text entry interface supported both letters-only and word prediction enhanced typing conditions. Sentences were presented in blocks of five with blocks ordered randomly via a Latin square.

3.1 RESEARCH QUESTION 1: ACTION SEQUENCES

Do individuals establish consistent sequences of actions used to interact with the system?

Predictable behavior is essential in order to achieve accuracy with modeling techniques. Ideally an individual would execute the same sequence of actions each time a particular task was performed. In a variation which is still conducive to modeling, an individual would establish clear guidelines for the selection of sequences of actions used to perform a particular task. The selection would be based on one or more quantifiable properties of the task. The GOMS modeling techniques support this notion with selection rules which identify the methods used to perform a task.

All one and two fixation sequences in the collected data were tallied for each keystroke type for each participant. From these tallies, transitional frequency and probability matrices were created. In order to determine if the identified sequences occurred by chance or if sequences of behavior are truly indicated, the observed probability matrix was compared to a modified first order model. A z-score binomial test was performed to produce a matrix from which each z-score was examined for significance. Significant z-scores indicated that the corresponding sequence was a strategy adopted by the participant instead of simply a sequence of actions occurring by chance.

3.2 RESEARCH QUESTION 2: EFFECT OF EXPERIENCE

Does performance change as individuals gain experience using word prediction? As mentioned previously, accurate modeling relies on predictable performance by the individual. In the event that performance measures change as individuals gain experience using the system, static models created a priori or based on measures acquired prior to the individual interacting with the system would not accurately predict performance over the course of time.

Data collected for able-bodied participants solely was used in the analysis due to the limited and varying number of trials completed by participants with disabilities. Summary data was computed for each sentence trial within a block and then averaged on a per block basis. These averages were compared to determine if performance changed as the participant gained experience using the system. The effect of block order on text entry rate, keystroke rate, successful anticipation, and word prediction list search duration was examined. Significance was determined by performing a one-way repeated-measures ANOVA with $\alpha = 0.05$.

3.3 RESEARCH QUESTION 3: PERFORMANCE DIFFERENCES

How does performance differ for able-bodied individuals and individuals with disabilities? Differences in performance measures for able-bodied individuals and individuals with disabilities would indicate there is a need for models calibrated specifically for different user groups. While data for the able-bodied participants can be pooled together and used to represent the group, for a variety of reasons the data for the individuals with disabilities cannot. There were a limited number of participants and the individuals with disabilities differed to a great degree in diagnosis, severity and the amount of data collected. Due to these limitations, comparisons can only be made on a qualitative basis between the able-bodied group and the individual participants with disabilities. Table 2 shows the measures which were examined. These variables are defined in detail in the Analysis section on page 46.

Table 2. Data examined

text entry rate
keystroke rate
keystroke savings compared to letters only
keystroke savings compared to optimal letters only
keystroke savings compared to optimal word prediction
total error rate
uncorrected error rate
corrected error rate
utilized bandwidth
wasted bandwidth
successful anticipation
successful list search time
unsuccessful list search time
positive list search time
false positive list search time
fixations on presented text
fixations on transcribed text
fixations on the on-screen keyboard

The mean for each of the identified variables of interest was computed on a per block basis. A block consists of five trials; each sentence is a trial. Data for all of the blocks completed by the able-bodied participants was used to calculate a mean and 95% confidence interval for the group for each variable. On an individual basis, the data for each of the participants with a disability was used to calculate a mean and 95% confidence interval for each variable. Note that data for Participant 4 is missing in some comparisons as this participant only completed a single block with the letters only typing condition thus precluding the computation of a confidence interval. The data for the able-bodied group and each of the participants with disabilities was plotted together for the purpose of comparison. This approach inherently accounts for the difference in the amount of data collected while providing an indication of how performance differed between able-bodied and individuals with disabilities.

3.4 RESEARCH QUESTION 4: FEASIBILITY OF MODELING

Can models be created based on the collected data?

The feasibility of creating models of any type is dependent on consistent behavior by the user. Sequences of actions and consistent times for performing primitive operations are critical components. The first research question examined the existence of action sequences. Primitive operations can include operations at various levels of granularity with a finely grained analysis breaking a key press down into components including the time for the decision to perform the action. The data collected in this study was examined for consistency at a much higher level. Consistency in time between keystrokes and word prediction list search durations were examined by calculating confidence intervals.

Confidence interval data for time between keystrokes and word prediction search durations were used to show the uncertainty of predictions made by Koester and Levine's (18) KLM model of performance with word prediction. This demonstration of the range of resulting predictions was used to illustrate the difference between performance predictions made for able-bodied and individuals with disabilities.

4.0 INSTRUMENTATION

The test bench consists of two computers running seven software applications. Main components include a text entry interface developed in house which records time stamped keystroke events and a system which collects time stamped eye fixation data. The text entry interface, which supports word prediction, is used as an example of the type of operations that users typically perform when using a computer. The environment simulates an array of demands placed on the individual and their corresponding responses. The participants were asked to type quickly and accurately using an on-screen keyboard. The use of artificial strategies was neither imposed nor encouraged. An on-screen keyboard was used in order to keep the participant's eyes on the computer monitor throughout the test thereby simplifying the collection of eye tracking information. The test setup is described in detail in the following sections. Figure 1 is a digital photo of the system.

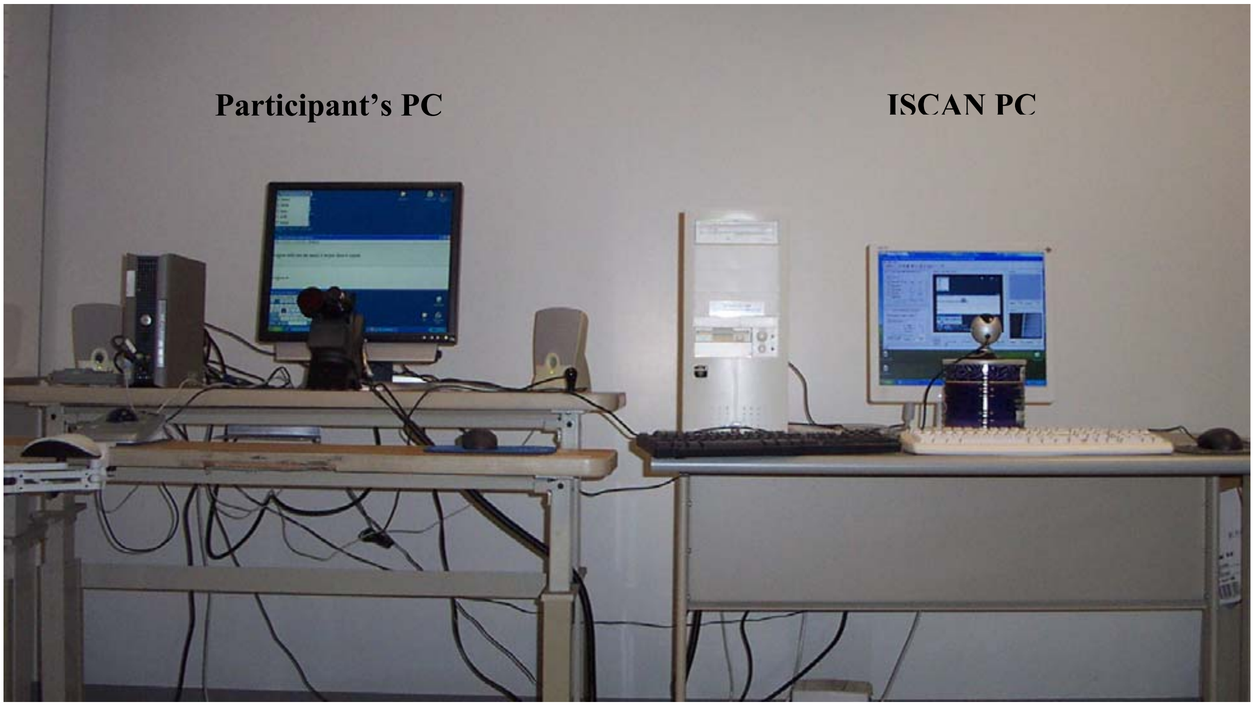


Figure 1. Test setup

4.1 THE PARTICIPANT'S PC

The participant was asked to use an on-screen keyboard to transcribe sentences within a text entry interface which supports both letters only and word prediction enhanced typing. Screen resolution was set to 1024x768 pixels to make the applications easy for the user to view while maintaining an appropriate distance for the eye tracker to collect data. This resolution is also recommended when using the Morae Recorder which will be explained in a later section. A photo and screen shot of the participant's PC are shown in Figure 2 and Figure 3 respectively.

Figure 2. Photo of participant's PC

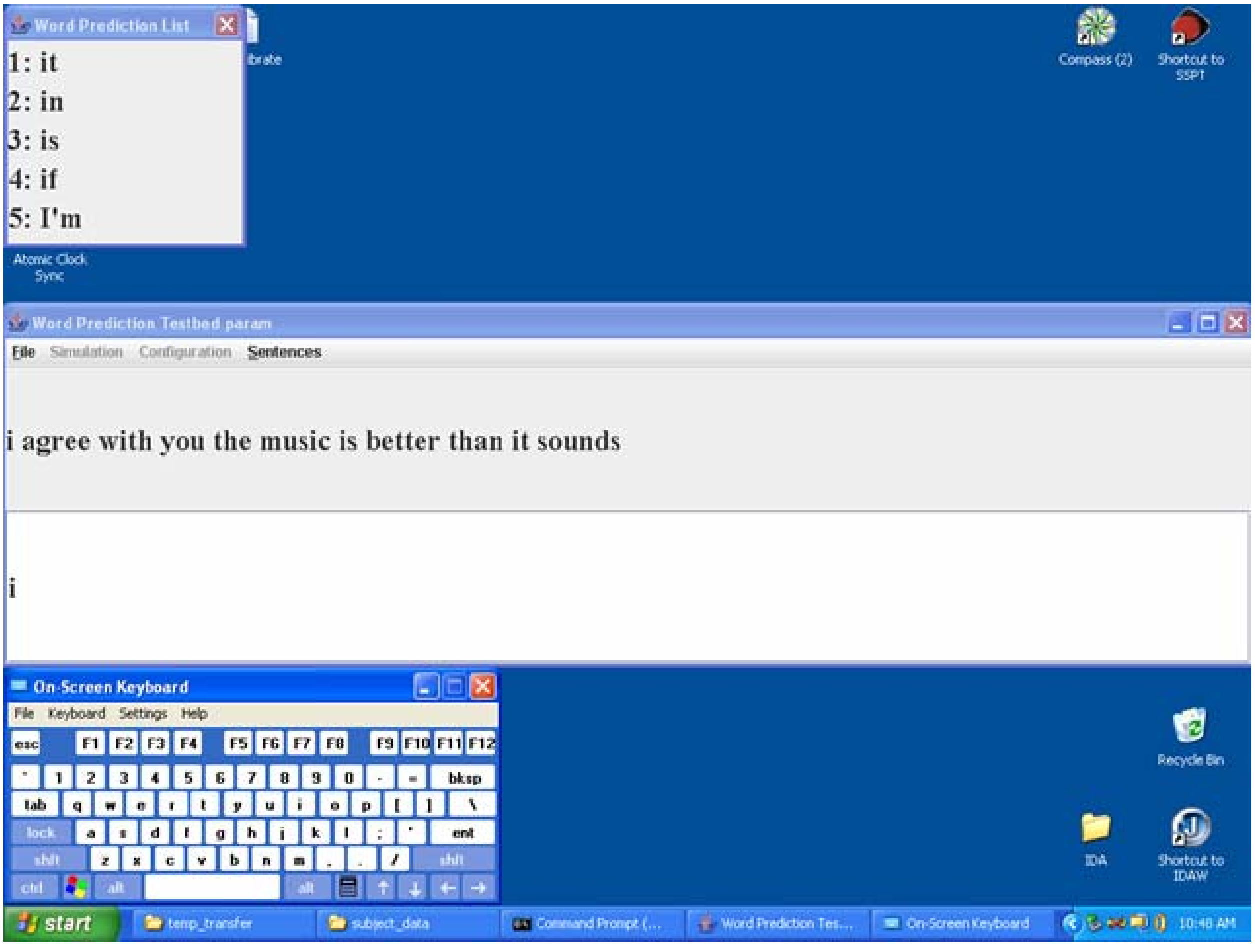


Figure 3. Screen shot of participant's PC

4.1.1 Text Entry Interface

The foundation of the test bed is a text entry interface which supports letters-only and word prediction enhanced typing with numerous configurations. The program is written in Java and requires the J2SE runtime environment. Figure 3 shows the application with word prediction active.

For the purposes of this study, when word prediction was active the configuration was set to always show the prediction list with a maximum list length of five words. The application presents sentences in groups of five for the user to transcribe while keystrokes are collected, time stamped, and written to a log file. Sentences used by the interface are representative of the English language; they are combinations of phrases from the set identified by MacKenzie and Soukoreff (21). Sentences are limited to lower case and contain no punctuation as inclusion of these elements acts as a confounder when variations are found in dependent measures (21). Analysis of the sentences produces the profile shown in Figure 4.

```
---------------------------------------
phrases: 50
minimum length: 50
maximum length: 55
average phrase length: 52.3
---------------------------------------
words: 517
unique words: 302
minimum length: 1
maximum length: 14
average word length: 4.15
words containing non-letters: 0
---------------------------------------
letters: 2615
correlation with English: 0.9516
```

Figure 4. Profile of presented text

Appendix A contains an example output file from the text entry interface.

4.1.2 On-screen Keyboard

Selection of the on-screen keyboard was based on the text entry rate achieved by the participant during practice trials. Practice trials were performed with the Microsoft Windows XP on-screen keyboard. For participants performing the practice transcription below 0.65 char/sec (8 words/min), the keyboard was changed to WiViK in an attempt to simplify the transcription process by providing larger targets on the keyboard. Figure 5 shows a screen shot of the participant's PC with the WiViK on-screen keyboard. Note that the word prediction feature in WiViK is disabled.

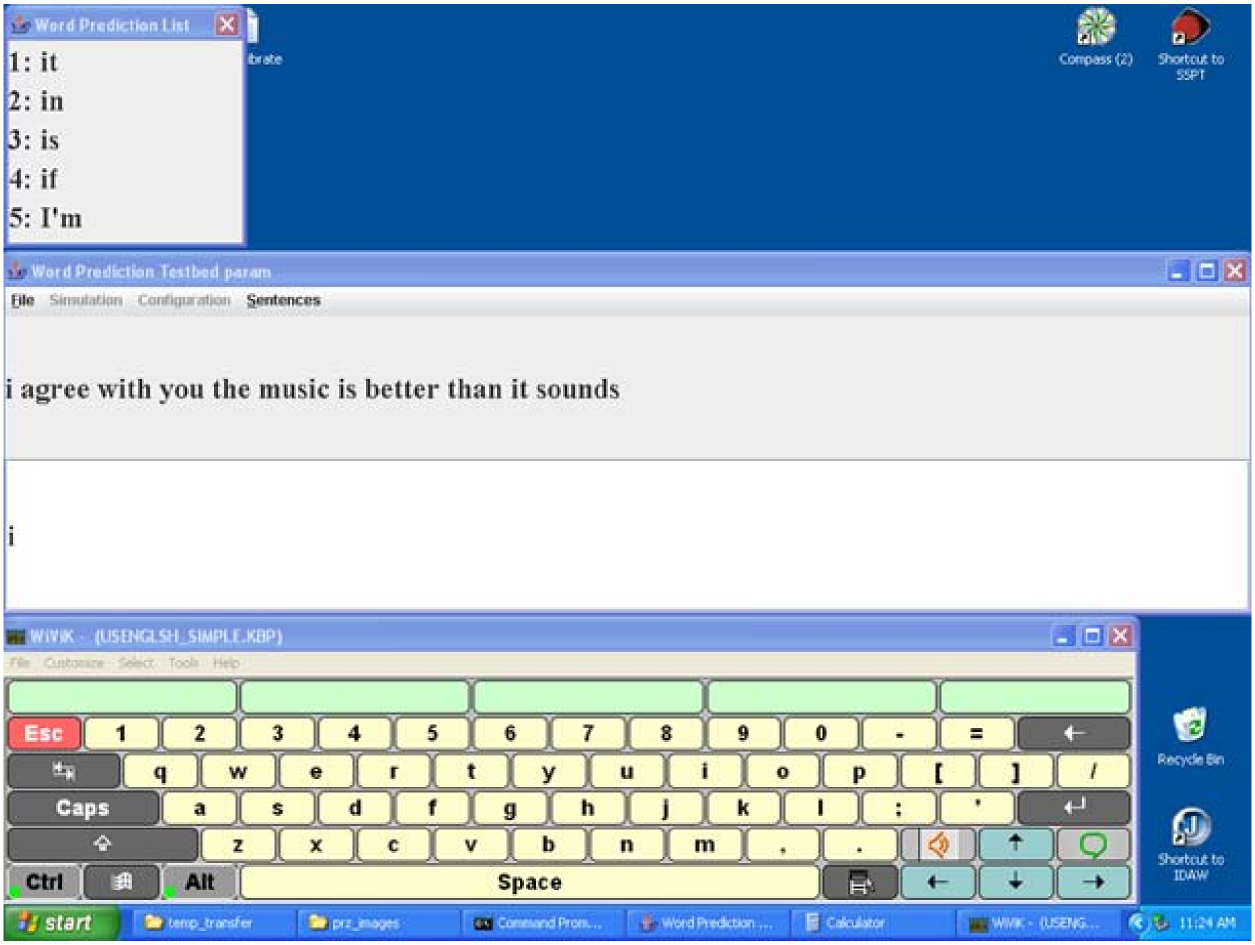


Figure 5. Screen shot of participant's PC with WiViK on-screen keyboard

4.1.3 Morae

The test session was recorded using Morae, usability test software produced by TechSmith. The software consists of two components, a recorder used to control data capture and a manager used for project creation, playback, and interaction. The recording contains all desktop activity including time stamped events, screen capture of the entire desktop, and a webcam video which can all be replayed in sync with each other. The webcam was set up to record data on the eye tracking machine which will be discussed in a later section. Appendix B contains further details concerning the Morae configuration.

Figure 6 is a screen shot of the Morae Manager with a project containing data for one of the participant's trials open. The playback data includes a screen capture of the entire desktop with a red arrow indicating the active window. Below the screen capture is a list of the time stamped keystroke and windows system events. To the left is the webcam video of the ISCAN machine. The current location of the participant's eye gaze is circled in red and labeled as "point of regard".

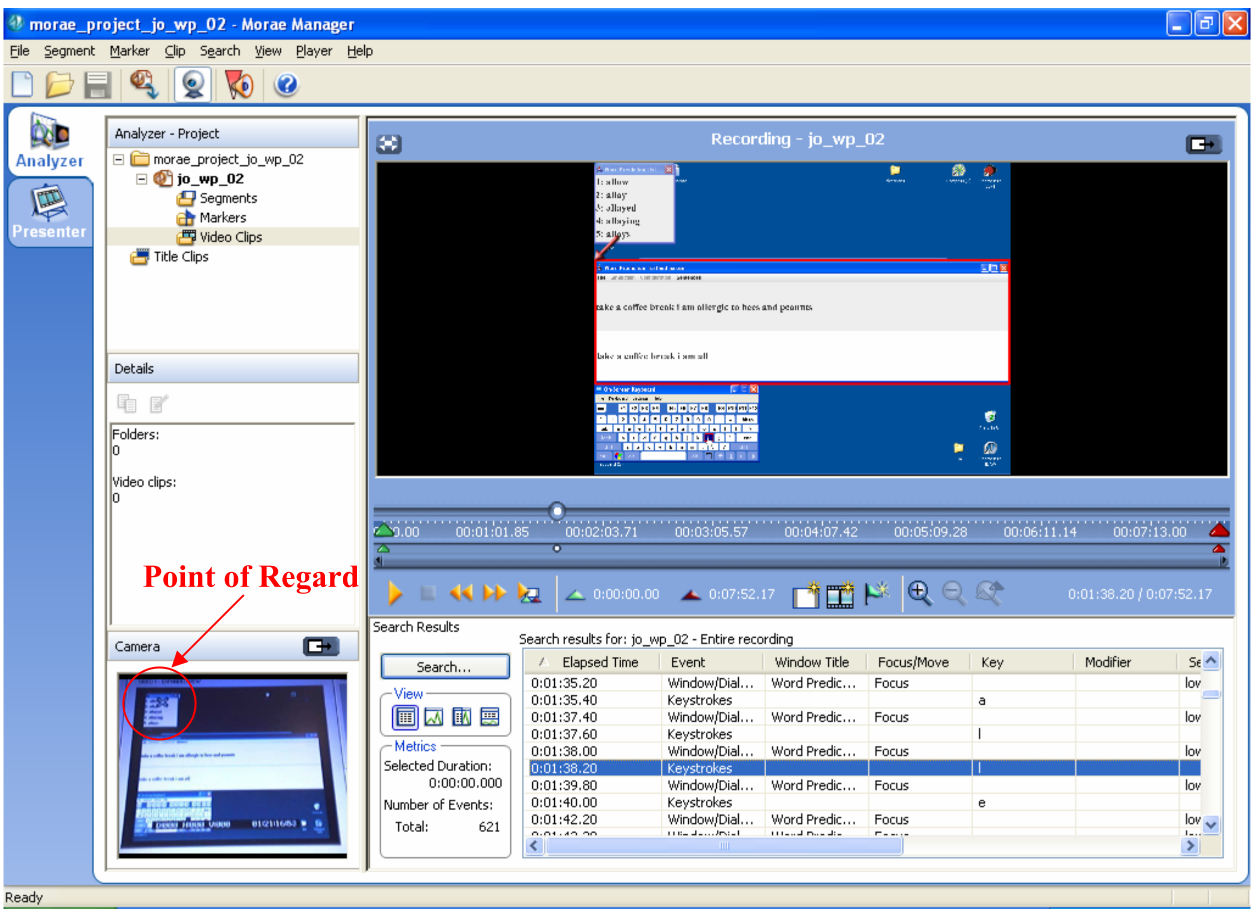


Figure 6. Screen shot of Morae Manager playback

In the example shown, the participant is in the process of transcribing the word “allergic”. The current event is a keystroke of the letter ‘l’; the cursor is shown on the ‘l’ key of the on-screen keyboard. The text entry application is the active window receiving keystrokes in the transcribed text area. The word prediction list appears in the upper left corner of the screen. The camera view in the lower left of the manager window shows that the participant’s point of regard is on the word prediction list.

4.1.4 Atomic Clock Sync

In order to allow the time stamped data from the two computers to be combined, each computer must have its clock synchronized. Atomic clock sync is a free utility that was run to ensure the computer is up to date with the exact current time. Figure 7 is a screen shot of the clock sync application. Clicking on the “Ping Now” button initiates a comparison between the PC clock and the exact current time.

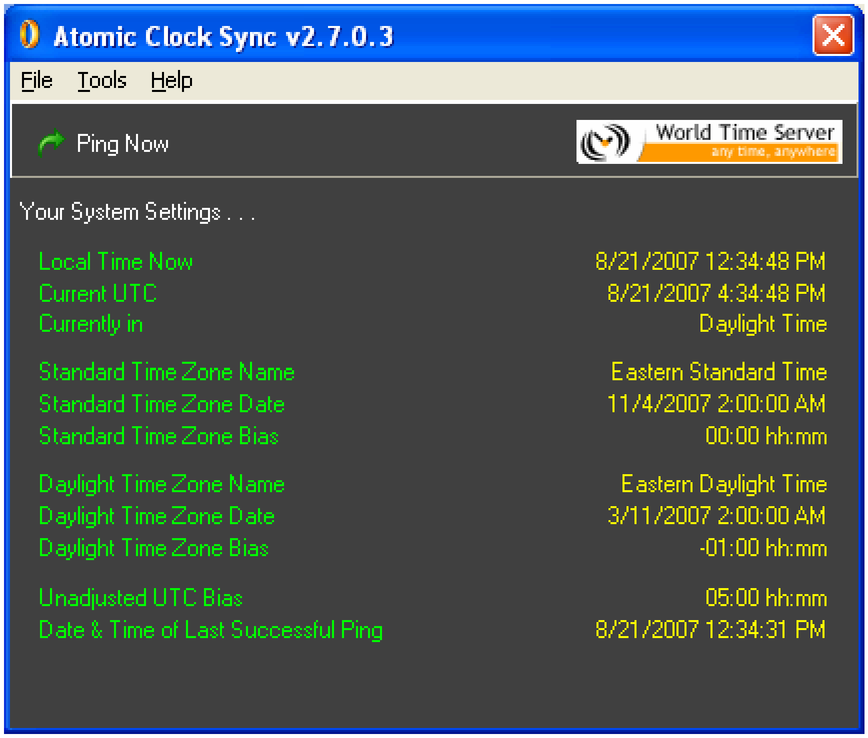


Figure 7. Screen shot of Atomic Clock Sync

4.2 ISCAN PC

The second computer contains hardware and software to record eye tracking information. This machine is dedicated to ISCAN hardware and software and is only connected to the Internet by a wireless USB 2.0 network adapter for anti-virus software updates, participant data transfer, and atomic clock sync. Figure 8 is a digital photo of the ISCAN PC.

Figure 8. Photo of ISCAN PC

4.2.1 Hardware

As shown in Figure 9, a remote camera referred to as the eye imager is positioned directly in front of the participant's PC facing the participant and connected to a card in the ISCAN PC. The eye imager consists of an infrared light source and a camera.

The monitor input from the participant's PC is run through a DVI (digital video in) to VGA (video graphics array) converter which connects to an AVerKey iMicro necessary to provide the video input to the RK-630 PCI card in the ISCAN PC. This card provides the ISCAN software with a picture of the scene the participant is viewing on which a cursor marking point of regard is superimposed in real time. As mentioned previously in the section describing Morae and shown in Figure 8, this scene was recorded by a webcam and stored as part of the Morae recording.

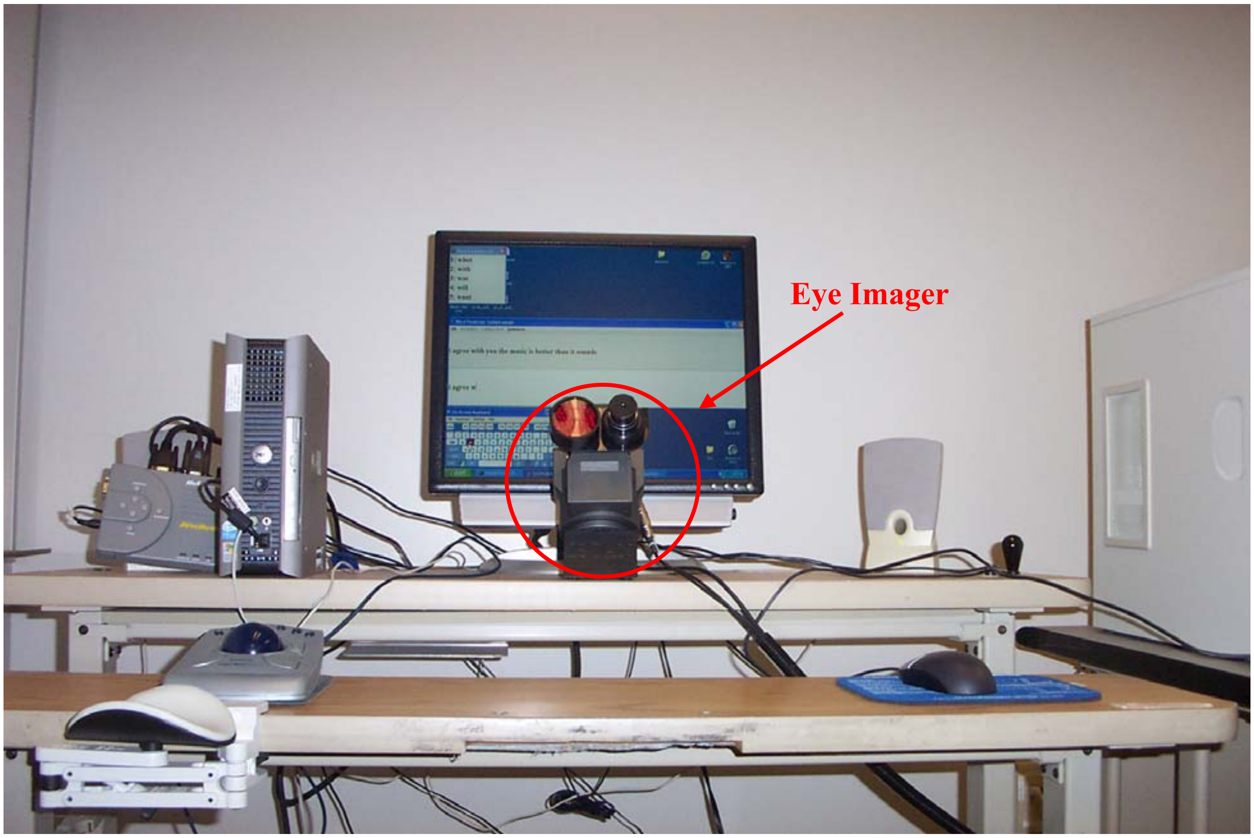


Figure 9. Photo of participant's PC

4.2.2 Software

4.2.2.1 DQW – ISCAN Raw Eye Movement Data Acquisition Software

This application was used to control system calibration, data capture, real time data viewing, and storage. Figure 10 is a screen shot of the application during data acquisition.

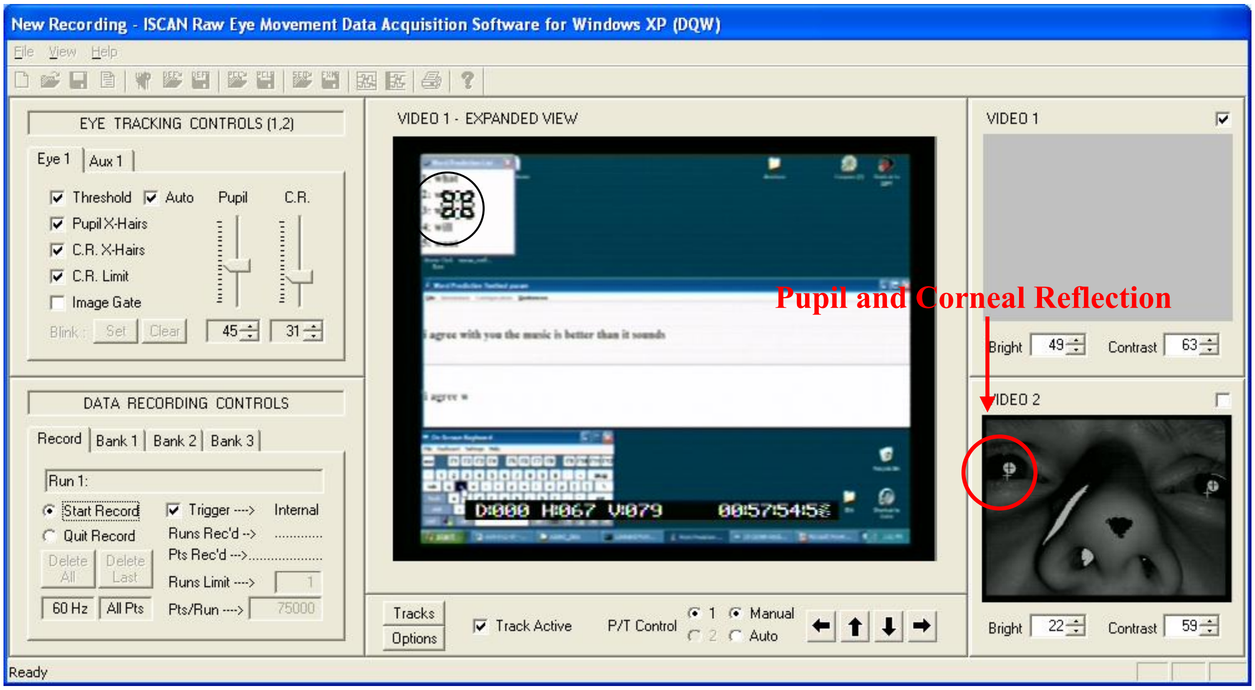


Figure 10. DQW screen shot

The center pane which is labeled "VIDEO 1 – EXPANDED VIEW" shows the current activity on the desktop of the participant's PC with a cursor showing the participant's current point of regard which was on the word prediction list when the screen shot was taken. The horizontal and vertical coordinates of the current point of regard are shown near the bottom along with a timestamp. VIDEO 2 is the view from the eye imager with crosshairs overlaid which show the current position of the participant's pupil and corneal reflection for each eye. In the lower portion of the middle pane are the track active checkbox and the camera controls. The pan / tilt control can be adjusted automatically by the DQW software or manually using the arrows to the right. The auto adjustment worked relatively well as long as the participant's movement was slow and smooth. This option did not work well for participants with spastic CP. In these cases the researcher had to manually adjust the camera pan / tilt frequently. The eye tracking controls appear in the upper left; these settings are used for detection of the participant's pupil and corneal reflection for each eye. The auto adjustment worked well for most participants, those with glasses seemed to require more manual adjustment. The data recording controls appear in the lower left pane. These controls are used to initiate and terminate data capture. Appendix C contains examples of the output files generated by this application.

4.2.2.2 PRZ – ISCAN Point of Regard Data Analysis Software

This application was used primarily for data viewing purposes. Details concerning the use of this application are provided in Appendix D. Figure 11 is a screen shot of the PRZ display showing fixations identified from collected data overlaying the registered bitmap. The orange lines in the screen shot are saccades, rapid eye movements used to relocate the eye between fixations.

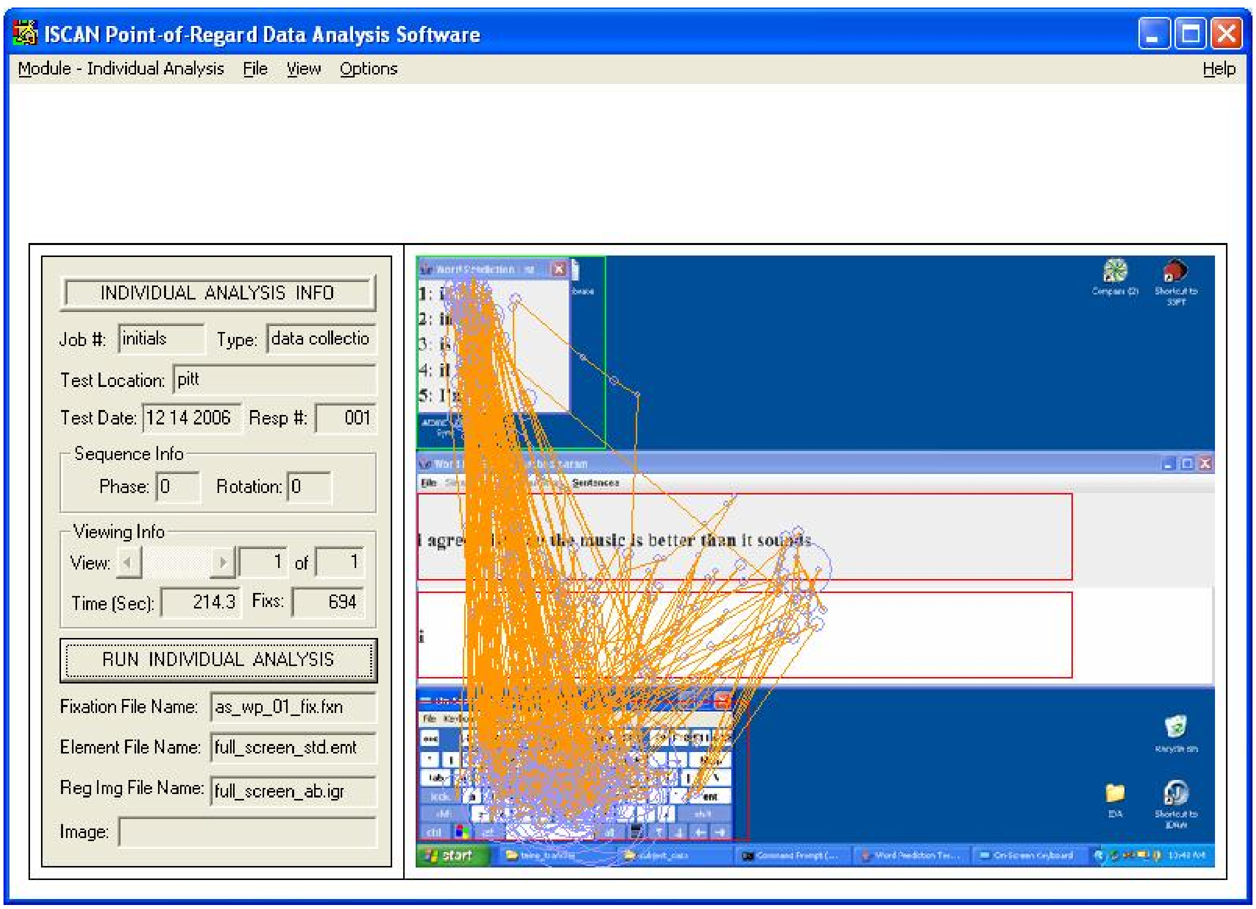


Figure 11. PRZ fixation viewing screen shot

4.2.2.3 Atomic Clock Sync

The computer must be connected to the Internet via the wireless network adapter in order to run the clock synchronization utility which is described in section 4.1.4.

5.0 METHODOLOGY

5.1 STUDY DESIGN

This study was exploratory research in the sense that collected data was examined to identify potential relationships among a variety of factors. Potential relationships between sequences of actions and resulting event types, performance measures and experience, and diagnosis and performance were examined.

5.2 PARTICIPANTS

Participants were recruited via posting an Institutional Review Board (IRB) approved flyer in Forbes Tower and word-of-mouth advertising.

5.2.1 Inclusion Criteria

Participants between the ages of 21 and 65 were recruited. Participants were required to possess the ability to use some form of hand operated pointing device (mouse, trackball, track pad, joystick, etc.), visual acuity to enable use of a computer with screen resolution set to 1024x768 pixels, and head control to maintain a stable position (movement of a few inches was acceptable) while performing tests.

5.2.2 Exclusion Criteria

Participants could not use bifocals or trifocals as their use could potentially require extensive head repositioning.

5.2.3 Participants

A total of eleven individuals participated in the study; the breakdown was five able-bodied individuals and six individuals with disabilities. Able-bodied participants are identified via letters while participants with disabilities are identified via numbers. Table 3 shows a summary of the primary diagnosis for the participants with disabilities.

Table 3. Primary diagnosis for participants with disabilities

Participant	Primary Diagnosis
1	Dwarfism & incomplete SCI (C5/6 and L1/2)
2	CP
3	SCI (C5/6)
4	CP
5	SCI (C5/6)
6	CP

5.3 PROTOCOL

Data was collected in a single session lasting approximately two hours. Participants were asked to transcribe sentences in blocks of five using an on-screen keyboard while maintaining a fairly stable head position (movement of a few inches). Breaks were offered between blocks. Able-bodied participants were asked to complete a minimum of 12 blocks comprising a total of 60 sentences. Participants with disabilities were asked to complete a minimum of six blocks comprising a total of 30 sentences. While participants were asked to complete a minimum number of sentences, in some cases they were not able to do so in the allotted time. Participant 2 in particular took an extremely long time for transcription, only completing seven sentences. Data for this participant was not used in analysis. Participant 4 only completed a single block of letters only typing which was not enough to calculate confidence intervals for that typing condition. Participants 1 and 5 were able to complete more trials than requested. Table 4 shows the number of sentences completed by each participant.

Table 4. Number of sentences transcribed by each participant

Participant	Number of Sentences Transcribed
A	60
B	60
1	40
2	7
C	60
3	30
D	60
4	25
E	60
5	80
6	30

The order of the sentence blocks and the configuration (letters only, word prediction) were selected randomly based on a 6x6 Latin square for able-bodied participants and a 3x3 Latin square for participants with disabilities (22). Table 5 is the 6x6 Latin square with each column showing the order of sentence block transcription for a participant. The word prediction typing condition was used for 10 blocks; the letters only typing condition was applied to two blocks.

Table 5. Order of sentence block transcription and typing condition

Participant	A	B	C	D	E
	blocks 9 + 10	blocks 1 + 2 (letters only)	blocks 7 + 8	blocks 5 + 6	blocks 3 + 4
	blocks 11 + 12	blocks 3 + 4	blocks 9 + 10	blocks 7 + 8	blocks 5 + 6 (letters only)
	blocks 1 + 2	blocks 5 + 6	blocks 11 + 12	blocks 9 + 10 (letters only)	blocks 7 + 8
	blocks 3 + 4	blocks 7 + 8	blocks 1 + 2 (letters only)	blocks 11 + 12	blocks 9 + 10
	blocks 5 + 6 (letters only)	blocks 9 + 10	blocks 3 + 4	blocks 1 + 2	blocks 11 + 12
	blocks 7 + 8	blocks 11 + 12	blocks 5 + 6	blocks 3 + 4	blocks 1 + 2

5.3.1 Procedure

5.3.1.1 Setup

The test environment was set up prior to the arrival of the participant. Setup consisted of creating folders for data storage, initializing the applications, syncing the clocks on both PCs, and calibrating the ISCAN machine. Detailed instructions for setup are provided in Appendix E.

5.3.1.2 Informed Consent

When the participant arrived, a discussion occurred in which the details of the study and the protocol were discussed and the consent form was explained. The consent form is provided in Appendix F.

5.3.1.3 Questionnaire

The participant was asked to fill out the preliminary questionnaire in Appendix G and the consumer survey in Appendix H. This information was collected for the purpose of acquiring information about independent variables such as diagnosis and to identify potential confounding factors.

5.3.1.4 Positioning

An adjustable chair was provided for participants without wheelchairs. Adjustments were made to the chair seat to floor height and armrest height for the comfort of the participant. An Ergorest adjustable support was available to provide an armrest for participants with manual wheelchairs. The PC was on a two level height adjustable computer desk to support adjustment for the participant's comfort. Participants sat upright in a comfortable position approximately one and a half to two feet from the ISCAN eye imager with their eyes hitting just below the midline of the computer monitor.

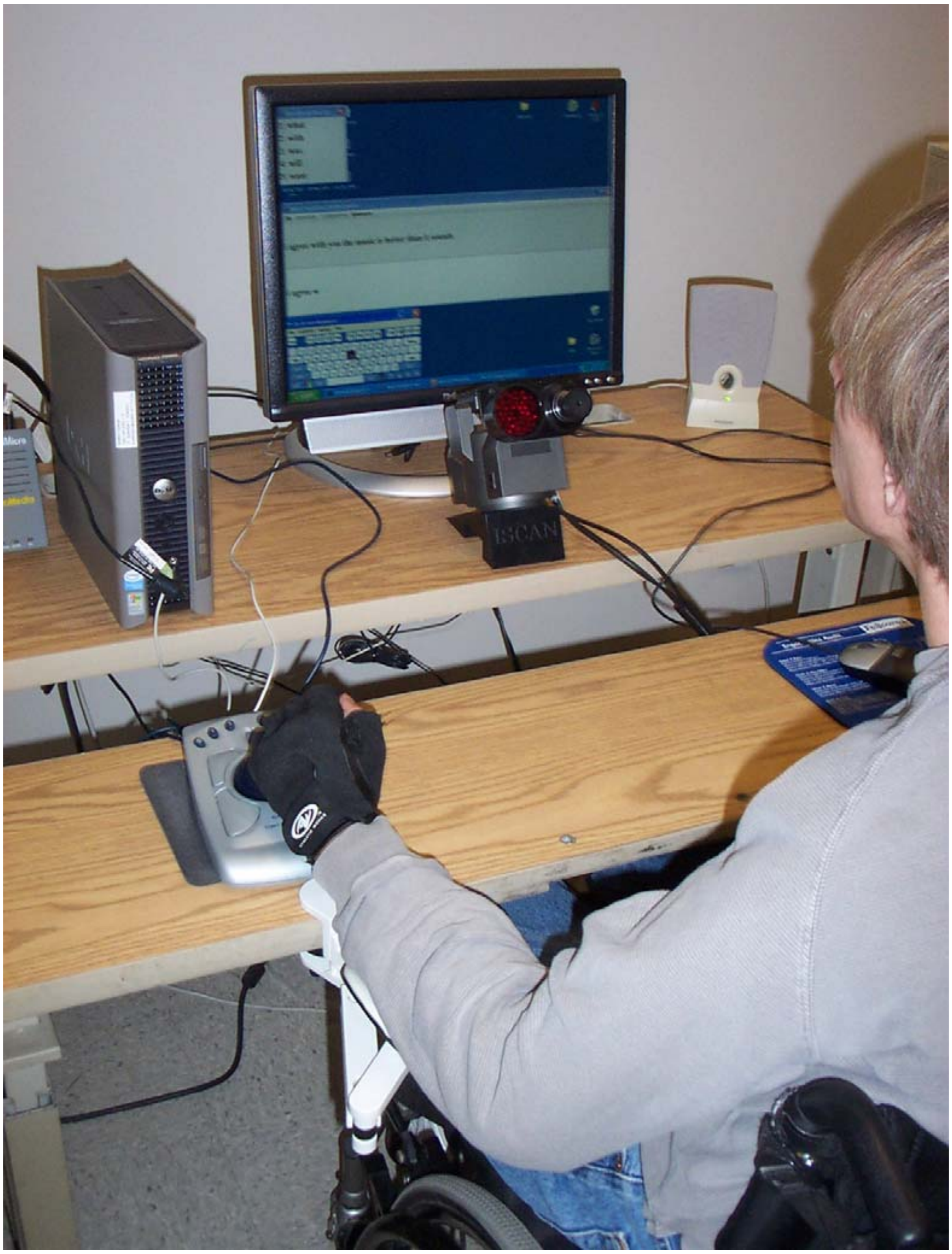


Figure 12. Photo showing positioning

5.3.1.5 Calibration

The ISCAN system required calibration for each participant. Calibration allowed the eye tracker to calculate the relative position of the pupil and corneal reflections for known locations. A power point calibration slide show was used to mark the areas of fixation required by the ISCAN equipment. The participant was asked to fixate on a point on each slide while the researcher initiated entry of the calibration point with the DQW controls. The calibration procedure is provided in detail in Appendix I.

5.3.1.6 Practice

The participant was given the opportunity to practice transcribing sentences using the test bench with word prediction active. Eye tracking was active during the practice trials but data was not saved. As mentioned in section 4.1.2, in the event that the text entry rate was below the cutoff, the on-screen keyboard was changed to WiViK and the practice session was repeated. This situation only arose for Participant 2 and as mentioned previously, the data for this participant was not used in analysis due to the limited amount collected. The practice procedure is provided in Appendix J.

5.3.1.7 Breaks

The participant was encouraged to take breaks between sentence groups and stretch. The system was recalibrated as needed based on the participant's movement.

5.3.1.8 Data Collection

Data collection began by starting the Morae Recorder so that the configuration for the text entry interface would be recorded in case of any questions after completion of the session. The text entry interface was then configured by selecting the sentence group to be transcribed and enabling or disabling word prediction depending on the specified typing condition. Eye tracking was set to active in the DQW application and the pan / tilt control was set to auto. The transcription test was started in the text entry interface and data recording was initiated in DQW. The participant transcribed a total of five sentences by typing with the on-screen keyboard while the researcher monitored the ISCAN display to confirm the participant's eyes were tracked properly and to make adjustments as needed. Adjustments were necessary as participants tended to shift and change position even while attempting to remain still. Data from both the text entry interface and DQW was saved upon completion of the last sentence in the block. The process was repeated for each block of sentences transcribed by the participant. The data collection procedure is provided in detail in Appendix K.

5.3.1.9 Data Storage

The data storage procedure is provided in Appendix L. Table 6 provides a brief summary of the data files created for each configuration (letters only and word prediction) - sentence group combination completed by the participant.

Table 6. Data files

Application	Filename	Contents
Text Entry	*configuration_sentencegroup*.wp	Time stamped keystroke events, wp list contents, summary measures
Morae	morae_project_*configuration_sentencegroup*\ *configuration_sentencegroup*.rdg morae_project_*configuration_sentencegroup*.mpr morae_project_*configuration_sentencegroup*.psc morae_project_*configuration_sentencegroup*.ptc morae_project_*configuration_sentencegroup*.ptcf morae_project_*configuration_sentencegroup*.stv	Entire Morae project – time stamped events, screen capture, webcam video
ISCAN DQW	*configuration_sentencegroup*_raw.tda *configuration_sentencegroup*_fix.fxn	Point of regard data – screen coordinate samples Fixation data – fixation sample numbers and screen coordinates
ISCAN PRZ	*configuration_sentencegroup*_fix_list.txt	Fixation data – area, coordinates, start time, duration

5.4 DATA MANAGEMENT

As indicated in the data storage procedure, all electronic data was backed up on the School of Health and Rehabilitation Sciences network drive under Simpson Lab\Jen\subject_data. The consent, questionnaire, and survey forms were stored in a locked cabinet in Dr. Simpson's office.

6.0 DATA

6.1 DEPENDENT VARIABLES

Table 7 summarizes the dependent variables measured in the study on a per sentence basis. These measures were provided as data output from the test bench and were used in subsequent data analysis either directly or to calculate other metrics as defined in the data analysis section.

Table 7. Dependent measures

Variable	Definition
event sequences	strings of codes identifying fixations appearing in order of occurrence (per keystroke)
text entry rate	average number of characters produced in a second (char/sec)
keystroke rate	average number of keystrokes entered in a second (keystrokes/sec)
input stream (I)	sequence of keystrokes performed by the user
transcribed text (T)	final sequence of characters resulting from the keystrokes
incorrect fixed (IF)	errors in input stream but not appearing in transcribed text
incorrect not fixed (INF)	errors appearing in transcribed text
fixes (F)	keystrokes that perform corrections (backspace)
correct (C)	alphanumeric keystrokes that are not errors
positive list searches	number of times user searched the word prediction list when the target word was in the list (per sentence)
positive list search duration	total duration of word prediction list fixations when target word was in the list (per sentence)
false positive list searches	number of times user searched the word prediction list when the target word was not in the list (per sentence)
false positive list search duration	total duration of word prediction list fixations when target word was not in the list (per sentence)
negative list searches	number of times user did not search list when word was not in list (per sentence)
false negative list searches	number of times user did not search list when word was in list (per sentence)
presented text views	number of fixations on the presented text per sentence
transcribed text views	number of fixations on the transcribed text per sentence
on-screen keyboard views	number of fixations on the on-screen keyboard per sentence

6.2 ERRORS

6.2.1 Confounders

Potential confounders include visual acuity, fatigue, English language skills, short term memory capacity and experience with computers, word prediction software, and on-screen keyboards. Data concerning confounders related to experience was collected as part of the initial questionnaire but division of the participants into groups to control for the confounders was not practical for a couple of reasons. There were a limited number of participants and in much of the analysis, participants with disabilities were considered on an individual basis.

6.2.2 Measurement

The calibration of the ISCAN equipment, which appeared to drift as the machine heated up, was a significant source of measurement error. Additionally, calibration was much more difficult with some participants than others. The boundaries on the identified areas of interest were enlarged to accommodate difficulty in achieving accurate calibration for some participants. Difficulty in collecting accurate eye tracking data for some participants can be an issue for researchers using a variety of eye tracking systems. Schnipke and Todd (25) studied the use of eye tracking systems and found that only 37.5% of the participants in their study provided data which could be used in subsequent analysis.

6.2.3 Human Error

6.2.3.1 Researcher

Inclusion criteria for participation in the study did not specify that a participant's eyes must work together when objects on the screen are tracked and areas are fixated upon. Individuals with conditions that prevent their eyes from working together such as a lazy eye or crossed eyes should have been excluded from the study. This oversight became apparent when Participant 4 arrived and it was obvious that one of her eyes drifted and did not focus with the other eye. The ISCAN machine had great difficulty tracking her gaze and data collected for this participant is not considered reliable.

In the case of one participant, an error during data collection resulted in the loss of eye tracking data for the beginning of a trial. Eye tracking was lost for brief periods during data collection as many subjects shifted position. While the camera was readjusted either manually or with the automatic option immediately, data was still lost during the adjustment period.

6.2.3.2 Participant

In a couple of cases, participants inadvertently minimized or closed the text entry interface window resulting in the loss of data.

6.3 RAW DATA

6.3.1 Text Input

The input stream consisted of all of the keys that were pressed by the participant in the order that the keystrokes occurred.

6.3.1.1 Keystrokes (IF, INF, F, C)

Soukoreff and MacKenzie (23, 24) define the following four types of keystrokes:

- *Incorrect but fixed (IF)* keystrokes are erroneous keystrokes in the input stream that are latter corrected.
- *Incorrect and not fixed (INF)* keystrokes are errors that appear in the transcribed text.
- *Fixes (F)* are keystrokes such as backspace that perform corrections.
- *Correct (C)* keystrokes are alphanumeric keystrokes that are not errors.

6.3.1.2 Keystroke Types (FIX, WPSELECTION, LETTER, SPACE, TRANSITION)

The text entry interface logs keystrokes according to the following types:

- *Error correction (FIX)* keystrokes are keystrokes such as backspace which are used to correct errors.
- *Word prediction selection (WPSELECTION)* keystrokes are numeric characters entered to select a word from the word prediction list.
- *Letter (LETTER)* keystrokes are alphabetical characters.
- *Space (SPACE)* keystrokes are entered to produce spaces between words.

- *Enter (TRANSITION)* keystrokes are entered to indicate transcription of the current sentence has been completed.

6.3.2 Visual Fixations

Visual fixations are logged according to the area of the screen in which the fixation occurs and the duration of the fixation in seconds. The following areas appear in the PRZ log file:

- *Word prediction list* fixations occur within the boundaries of the dialog containing the word prediction list.
- *Presented text* fixations occur in the area where the sentence to be transcribed appears.
- *Transcribed text* fixations occur in the area where the text entered by the participant appears.
- *On-screen keyboard* fixations occur within the boundaries of the on-screen keyboard.
- *No element* fixations are those which occur outside the defined areas of interest.

Situations where an individual appears to be looking at something but is not really focused will be identified as fixations. This behavior confounds as data would appear to indicate increased cognitive load related to the transcription task when in reality the individual may have been fatigued or distracted by other thoughts.

6.4 POST PROCESSING

Perl scripts were written to perform post processing functions on the collected data such as combining the text entry and eye tracking data, and extracting pertinent performance summaries.

Perl was selected due to its strength in parsing and text manipulation. Version 5.6 of ActiveState ActivePerl was used. Appendix M contains detailed descriptions of the data files created by each of the Perl scripts. Table 8 summarizes the files which were used for subsequent data analysis.

Table 8. Post processing data files

Script	Filename	Contents
parse_word_data.pl	word_data.xls	Detailed keystroke and fixation data on a per character basis for words entered error free only
create_list_search_summary.pl	search_summary.xls	Summary of list search types, number of occurrences, and duration on a per sentence basis
parse_sentence_summary_data.pl	keystrokes.xls	Summary of keystroke types and error metrics on a per sentence basis
parse_sentence_summary_data.pl	keystroke_savings.xls	Summary of keystroke savings metrics on a per sentence basis
parse_sentence_summary_data.pl	text_entry_rate.xls	Summary of text entry rate on a per sentence basis
parse_sentence_summary_data.pl	keystroke_rate.xls	Summary of keystroke rate on a per sentence basis
parse_sentence_summary_data.pl	time_between_keystrokes.xls	Summary of time between keystrokes on a per sentence basis
parse_all_data.pl	all_data.xls	Event sequences for every keystroke (errors included)
parse_sequence_data.pl	sequence_summary.xls	Event sequences, number of occurrences, and probability of occurrence for each keystroke event type
parse_sequence_data.pl	sequence_analysis.xls	Transitional frequency matrices for each keystroke event type

7.0 ANALYSIS

7.1 MEASURES OF TEXT ENTRY PERFORMANCE

7.1.1 Speed

7.1.1.1 Text Entry Rate

The text entry rate (TER) was measured in each trial from the appearance of the presented text to the time the participant hit the <enter> key. TER focuses on the resulting text, ignoring text that was erased by the participant. TER also does not distinguish between text entered by the participant and text entered by word prediction.

TER = (length(T) + 1) / (transcription time) => char/sec

Table 9 contains the average text entry rate for each block of five trials for each of the able-bodied participants.

Table 9. Average text entry rate (char/sec) on a per block basis

	block1	block2	block3	block4	block5	block6	block7	block8	block9	block10
A	1.385	1.451	1.219	1.362	1.392	1.555	1.417	1.586	1.562	1.507
B	1.418	1.263	1.218	1.328	1.253	1.241	1.408	1.204	1.164	1.246
C	1.503	1.513	1.571	1.551	1.515	1.591	1.635	1.554	1.519	1.504
D	1.240	1.329	1.352	1.290	1.261	1.362	1.224	1.397	1.381	1.432
E	.858	1.026	1.005	1.070	1.162	1.091	1.087	1.055	.991	1.123

A one-way repeated-measures ANOVA was performed with $\alpha = 0.05$ to determine if block order had a significant effect on text entry rate. Results showed $p = 0.628$, indicating no relationship between block order and text entry rate.

Figure 13 shows the 95% confidence intervals for the average text entry rate (measured in chars/sec) for both of the typing conditions.

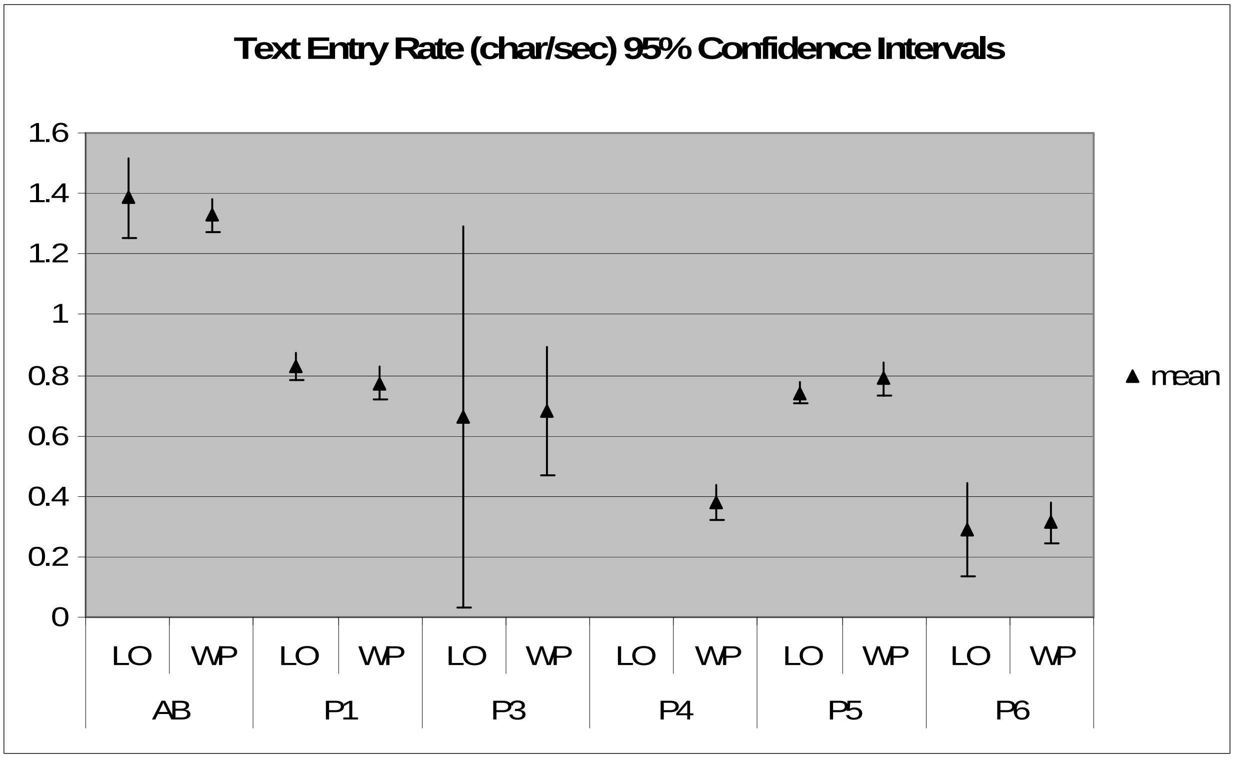


Figure 13. Text entry rate (char/sec) 95% confidence intervals

7.1.1.2 Keystroke Rate

Keystroke rate is the total number of keystrokes entered divided by the total amount of time for transcription in seconds. Keystroke rate is thus distinguished from TER in that it reflects all keystrokes generated by the user.

Keystroke rate = (total number of keystrokes) / (transcription time) => keystrokes/sec

Table 10 contains the average keystroke rate for each block of five trials for each of the able-bodied participants.

Table 10. Average keystroke rate (keystrokes/sec) on a per block basis

	block1	block2	block3	block4	block5	block6	block7	block8	block9	block10
A	1.216	1.291	1.212	1.202	1.125	1.165	1.079	1.162	1.267	1.153
B	1.131	.994	.960	1.094	1.004	.877	.961	.852	.948	1.056
C	1.513	1.503	1.571	1.597	1.538	1.613	1.635	1.595	1.602	1.559
D	1.219	1.291	1.308	1.229	1.498	1.360	1.501	1.424	1.324	1.265
E	.579	.614	.630	.717	.714	.724	.737	.750	.767	.762

A one-way repeated-measures ANOVA was performed at $\alpha = 0.05$ to determine if block order had a significant effect on keystroke rate. Results showed $p = 0.981$, indicating no relationship between block order and keystroke rate.

Figure 14 shows the 95% confidence intervals for the keystroke rate (measured in keystrokes/sec) for both of the typing conditions.

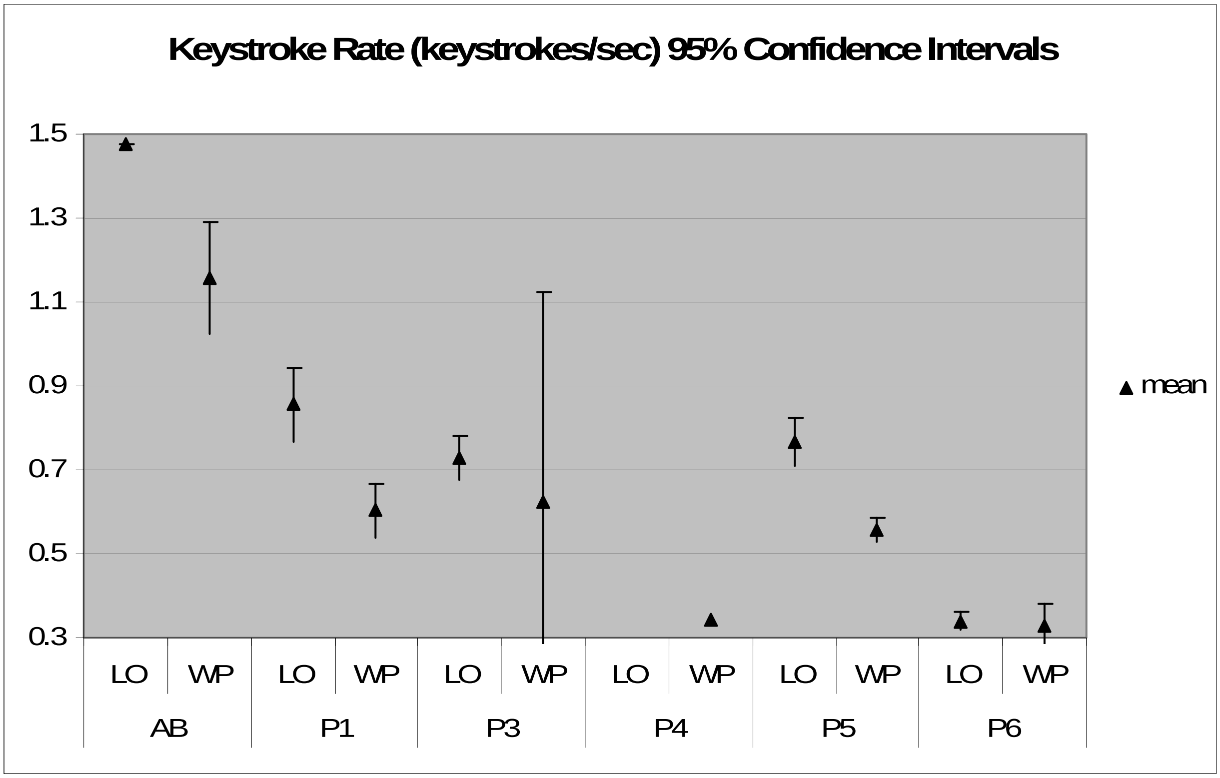


Figure 14. Keystroke rate (keystrokes/sec) 95% confidence intervals

7.1.1.3 Time Between Keystrokes

Confidence intervals for the time between keystrokes for blocks completed using letters only typing are shown in Table 11. This data was used as model parameters in subsequent analysis examining a proven KLM model. As stated previously, Participant 4 did not complete enough blocks of letters only typing to calculate a confidence interval for the time between keystrokes.

Table 11. Confidence intervals for the time between keystrokes (sec)

	to	from	average
able-bodied	0.740	0.606	0.673
participant1	1.189	1.083	1.136
participant3	2.055	0.517	1.286
participant4			
participant5	1.31	1.211	1.261
participant6	3.050	2.740	2.895

Figure 15 shows the 95% confidence intervals for time between keystrokes for both typing conditions.

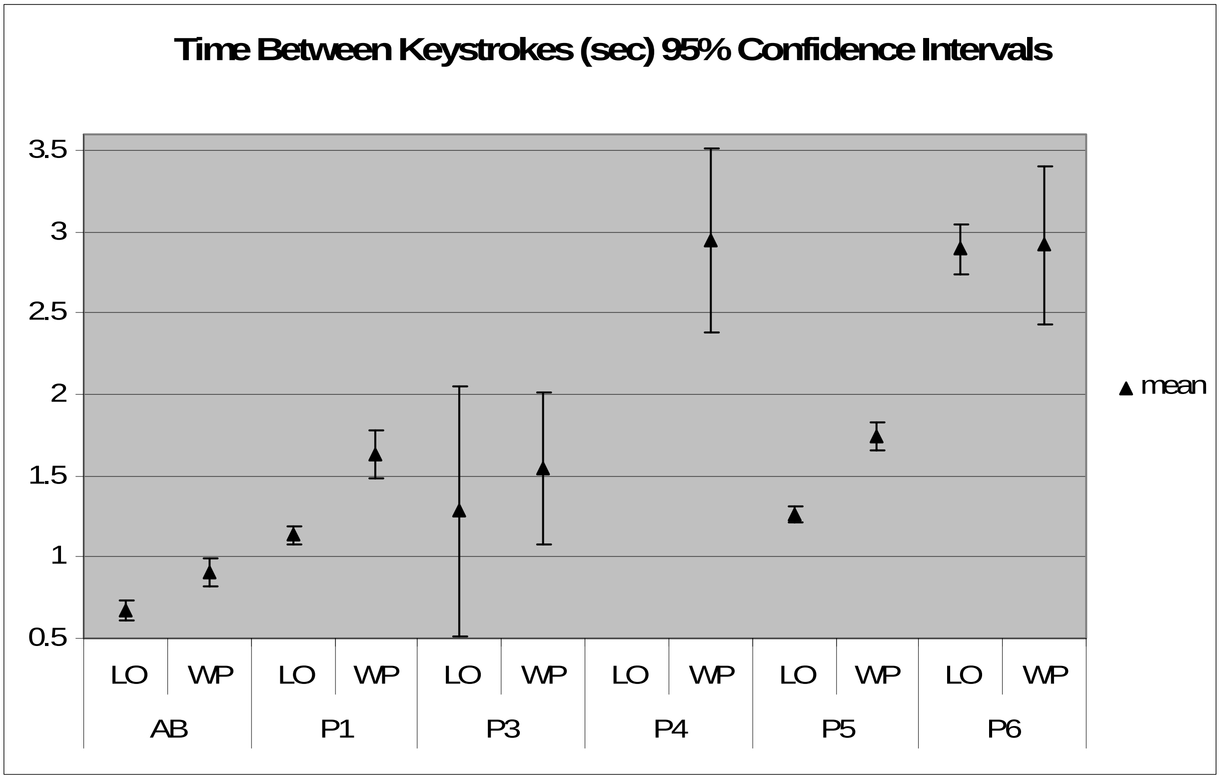


Figure 15. Time between keystrokes (sec) 95% confidence intervals

7.1.2 Errors

These metrics are presented as defined by Soukoreff and MacKenzie (23, 24).

7.1.2.1 Total Error Rate

Total error rate is the number of error keystrokes (both corrected and uncorrected) divided by the number of correct and error keystrokes. The rate expresses erroneous keystrokes as a percentage of total text producing keystrokes.

Total error rate = (INF+IF)/(C+INF+IF) x 100 => %

Figure 16 shows the 95% confidence intervals for the total error rate which is provided as a percentage for both typing conditions.

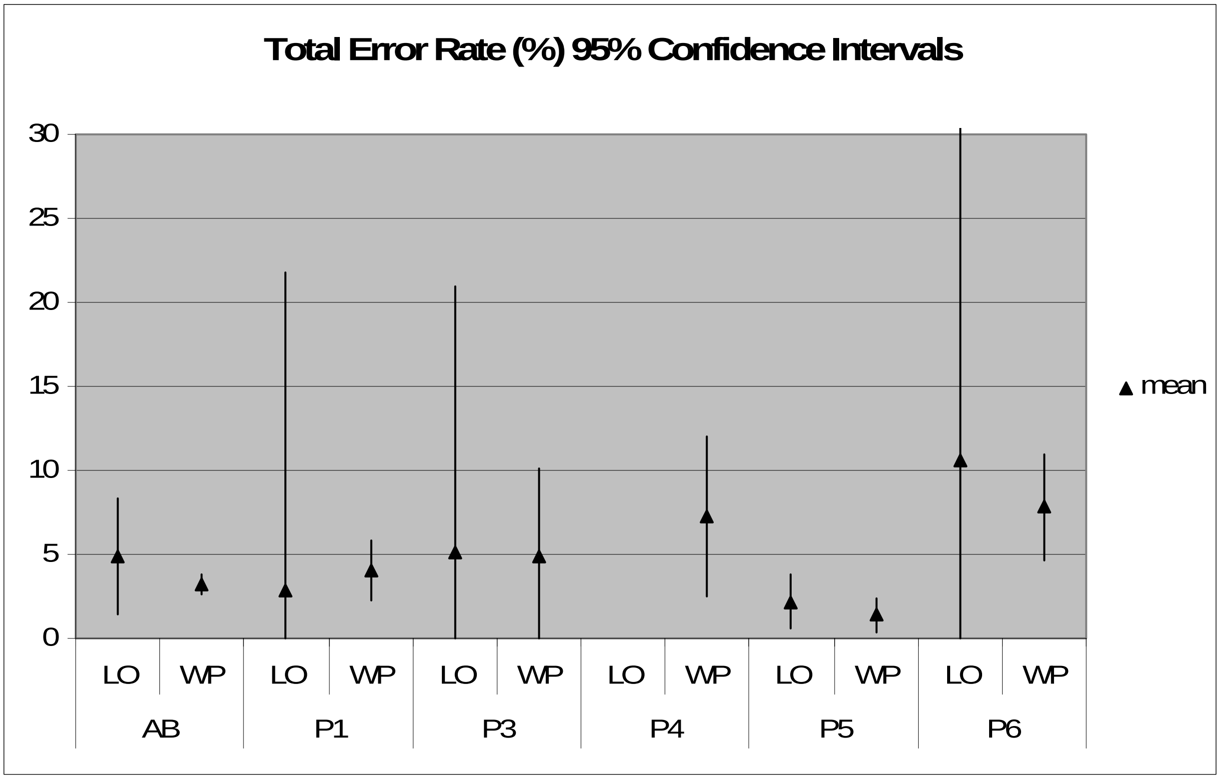


Figure 16. Total error rate (%) 95% confidence intervals

7.1.2.2 Uncorrected Error Rate

Uncorrected error rate is the number of uncorrected error keystrokes divided by the number of correct and error keystrokes. This rate is also expressed as a percentage of total text producing keystrokes.

Uncorrected Error Rate = INF/(C+INF+IF) x 100 => %

Figure 17 shows the 95% confidence intervals for the uncorrected error rate which is provided as a percentage.

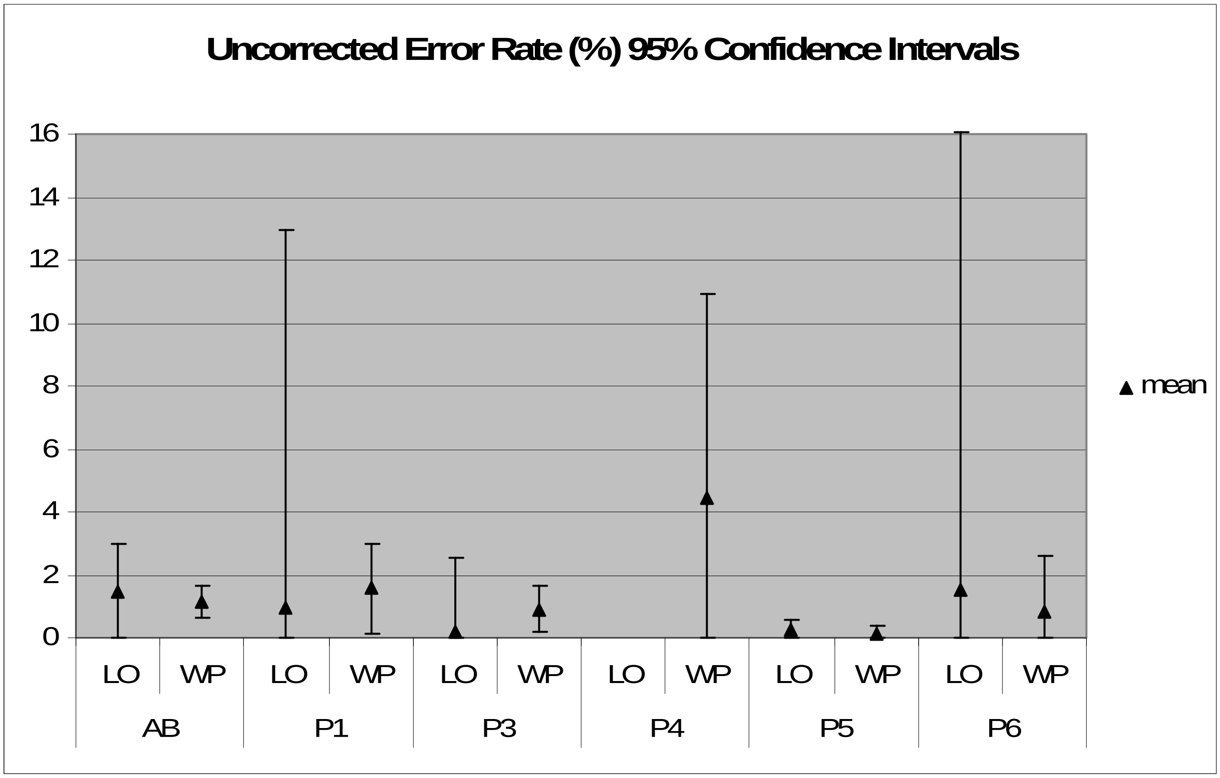


Figure 17. Uncorrected error rate (%) 95% confidence intervals

7.1.2.3 Corrected Error Rate

In a similar manner, corrected error rate is the number of corrected error keystrokes divided by the number of correct and error producing keystrokes. This rate is also expressed as a percentage of total text producing keystrokes.

Corrected Error Rate = IF/(C+INF+IF) x 100 => %

Figure 18 shows the 95% confidence intervals for the corrected error rate which is provided as a percentage.

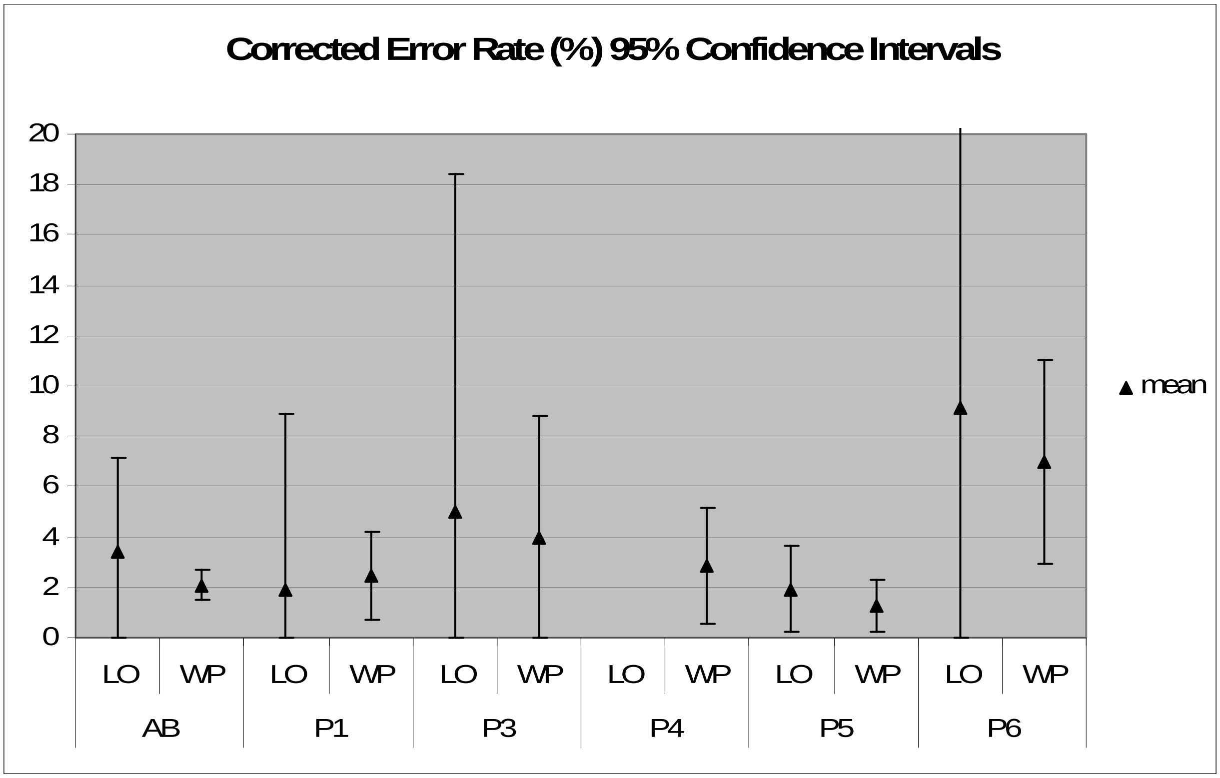


Figure 18. Corrected error rate (%) 95% confidence intervals

7.1.3 Bandwidth

7.1.3.1 Utilized Bandwidth

Utilized bandwidth is the proportion of bandwidth representing useful information transfer. As such, it is the number of correct keystrokes divided by the total number of keystrokes. Note that the total number of keystrokes includes "fixes" whereas in the previous metrics the denominator contained the total number of text producing keystrokes.

Utilized Bandwidth = C/(C+INF+IF+F)

Figure 19 shows the confidence intervals for utilized bandwidth or useful information transfer.

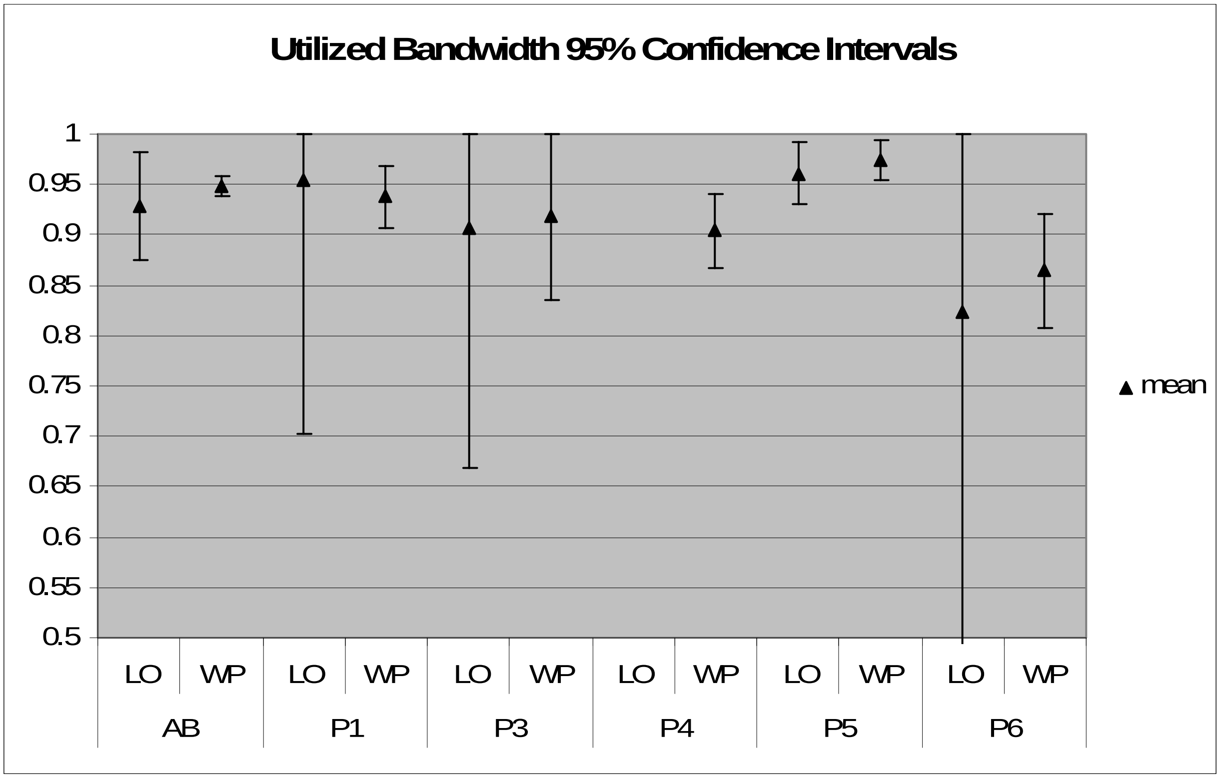


Figure 19. Utilized bandwidth 95% confidence intervals

7.1.3.2 Wasted Bandwidth

It follows that wasted bandwidth is the proportion of bandwidth used creating and fixing errors.

Wasted Bandwidth = (INF+IF+F)/(C+INF+IF+F)

Figure 20 shows the confidence intervals for wasted bandwidth.

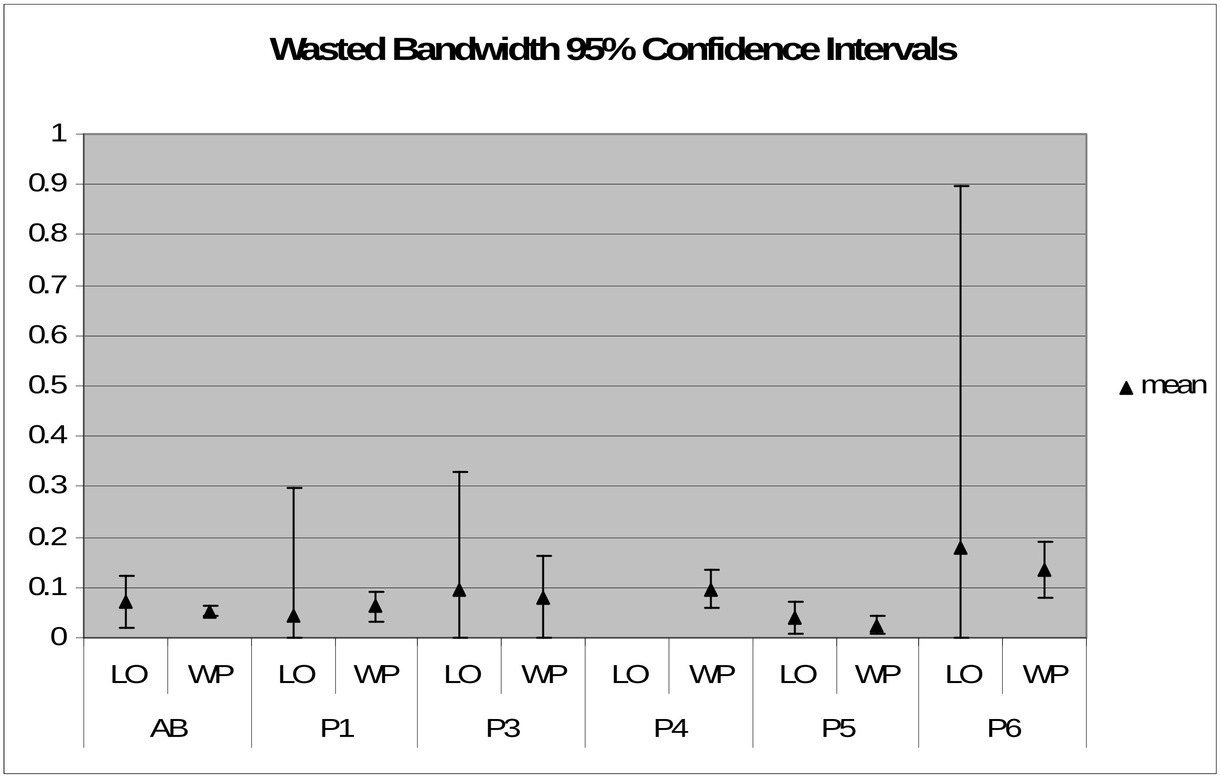


Figure 20. Wasted bandwidth 95% confidence intervals

7.2 MEASURES OF WORD PREDICTION USAGE

7.2.1 Keystroke Savings

The lengths of the presented text, input stream, and transcribed text were used to calculate keystroke savings.

length(T) = number of characters in the transcribed text

length(I) = number of keystrokes in the input stream

length(P) = number of characters in the presented text

7.2.1.1 Compared to Letters Only Typing

Keystroke savings compared to letters only typing reflects the difference between the number of keys pressed and the number of characters actually produced. If each keystroke in the input stream resulted in a character in the transcribed text, the keystroke savings is zero because the lengths of the input stream and the transcribed text are equal. If word prediction is used then the length of the input stream is less than the length of the transcribed text and keystroke savings is a positive number. If the user commits errors and engages in correction, the length of the input stream may be greater than the length of the transcribed text thus resulting in negative keystroke savings.

Keystroke savings compared to letters only = 1 – (length I) / (length T)

Figure 21 shows the 95% confidence intervals for the keystroke savings compared to letters only typing for each of the typing conditions.

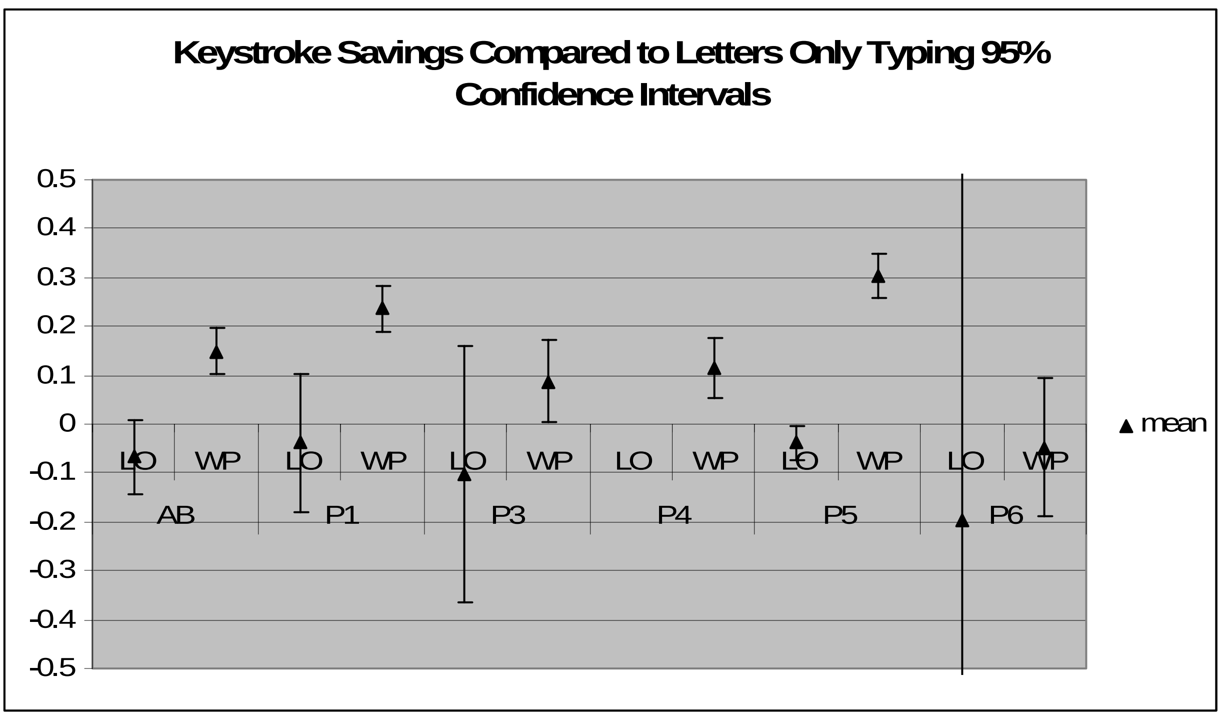


Figure 21. Keystroke savings compared to letters only typing 95% confidence intervals

7.2.1.2 Compared to Optimal Letters Only Typing

Keystroke savings compared to optimal letters only typing reflects the difference between the number of keys pressed and the number of characters in the presented text. Optimal letters only typing is such that the user transcribes the presented text exactly, thus requiring a single keystroke to enter each character in the presented text. In the event that this condition occurs, the keystroke savings compared to optimal letters only is zero. If word prediction is used then the length of the input stream is less than the length of the presented text and keystroke savings is a positive number. If the user commits errors and engages in correction, the length of the input stream will be greater than the length of presented text thus resulting in negative keystroke savings.

Keystroke savings compared to optimal letters only = 1 – (length I) / (length P)

Figure 22 shows the 95% confidence intervals for the keystroke savings compared to optimal letters only typing for each of the typing conditions.

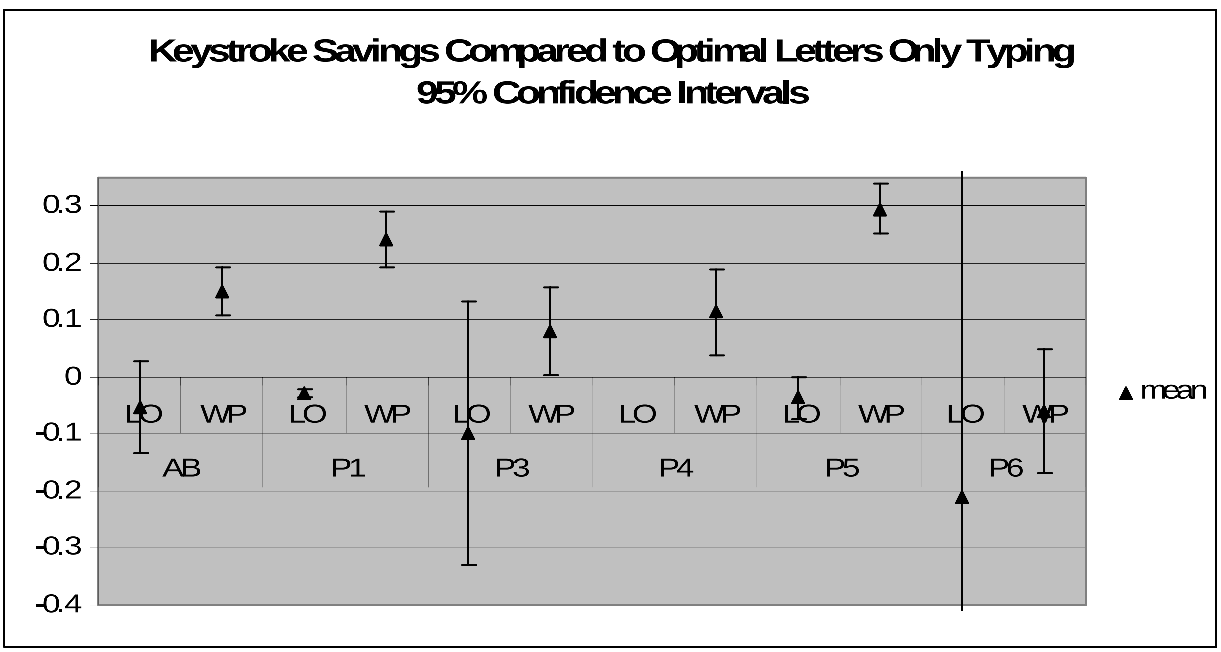


Figure 22. Keystroke savings compared to optimal letters only typing 95% confidence intervals

7.2.1.3 Compared to Optimal Use of Word Prediction

Keystroke savings compared to optimal use of word prediction reflects the difference between the number of keys pressed and the minimum number of keys needed if word prediction had been used to the fullest extent. The minimum number of keystrokes required (MKR) was obtained through using a strategy of always searching the word prediction list and selecting the target word immediately when it appeared in the list. If word prediction is used in this manner, then the keystroke savings would be zero. If word prediction is not used or is used in a less efficient manner, then the input stream is longer than the minimum and keystroke savings is negative.

keystroke savings compared to optimal wp = 1 - (length I) /(MKR)

Figure 23 shows the 95% confidence intervals for the keystroke savings compared optimal use of word prediction for each of the typing conditions.

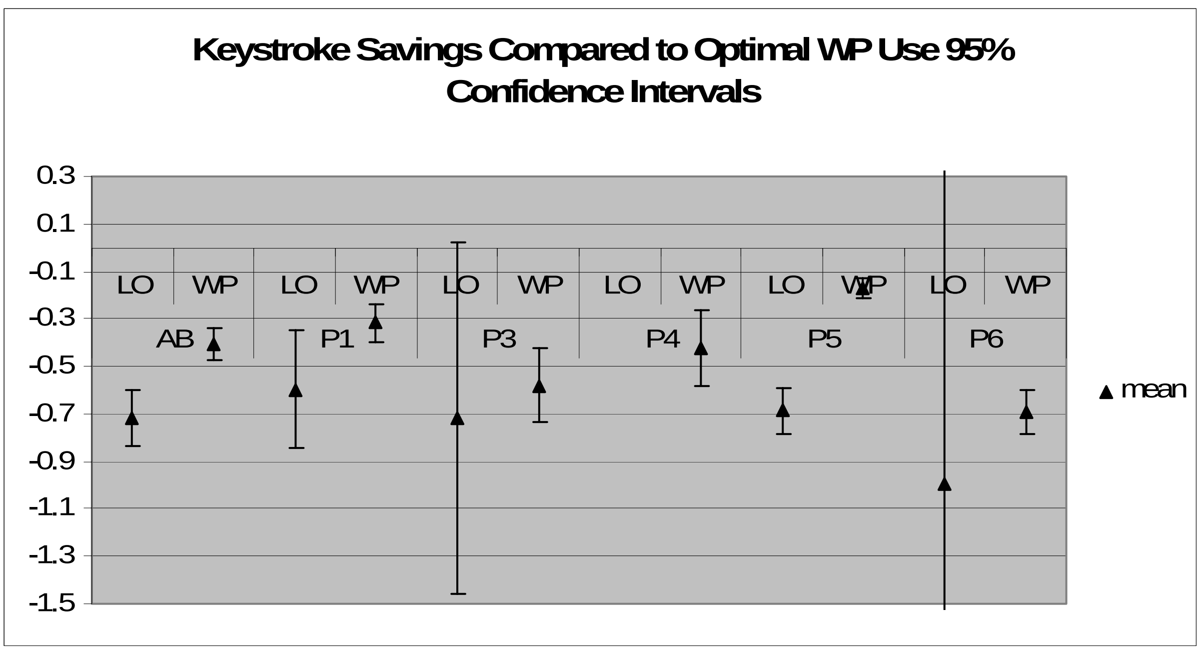


Figure 23. Keystroke savings compared to optimal wp use 95% confidence intervals

7.2.2 List Search

Data for word prediction list searches was classified based on detection of a fixation on the word prediction list in combination with the presence of the target word in the list. The number of occurrences and durations (where applicable) of the following types of searches were used in subsequent analysis:

Positive searches - the participant searched the list and the target word was in the list.

False positive searches - the participant searched the list and the target word was not in the list.

Negative searches – the participant did not search the list and the target word was not in the list

False negative searches – the participant did not search the list and the target word was in the list

Data relative to the list search types included the number of occurrences and total duration on a per sentence basis. This information was used to calculate the average time for a single list search for each positive search type on a per sentence basis.

7.2.2.1 Positive Searches

Figure 24 shows the 95% confidence intervals for the duration of a positive list search which is measured in seconds.

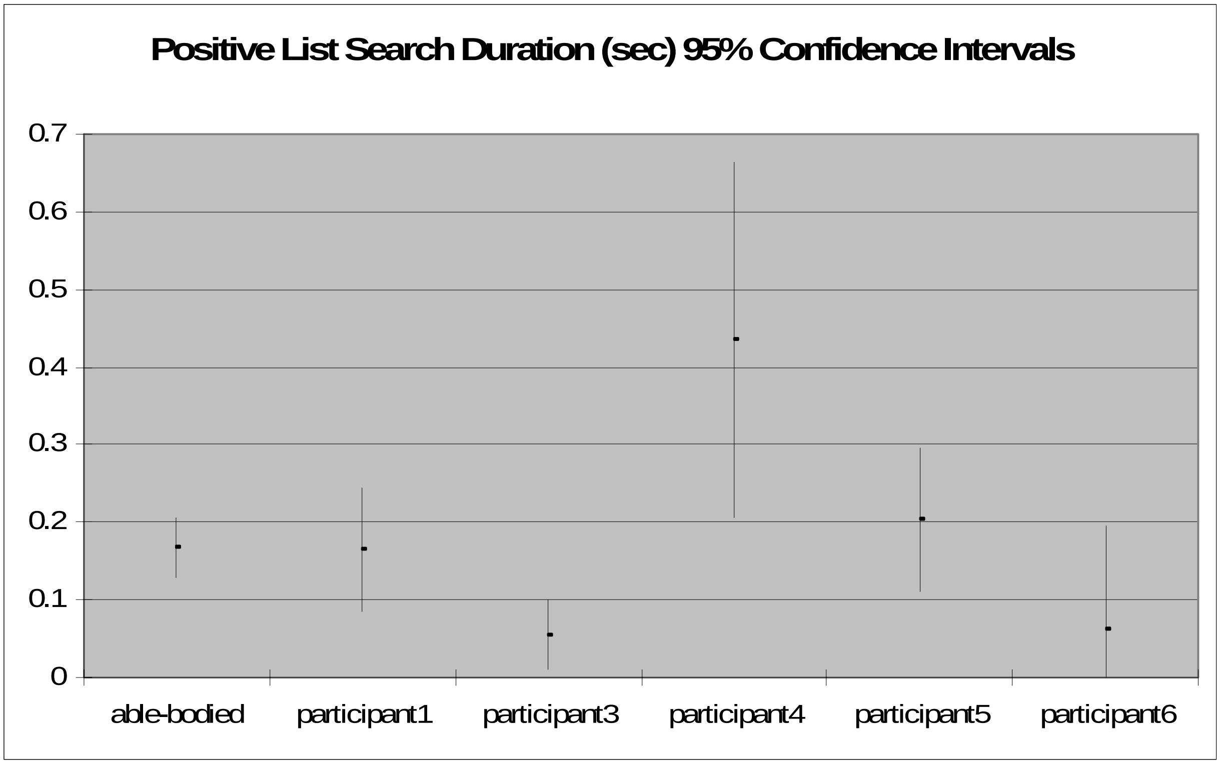


Figure 24. Positive list search time 95% confidence intervals

7.2.2.2 False Positive Searches

Figure 25 shows the 95% confidence intervals for the duration of a false positive list search which is measured in seconds.

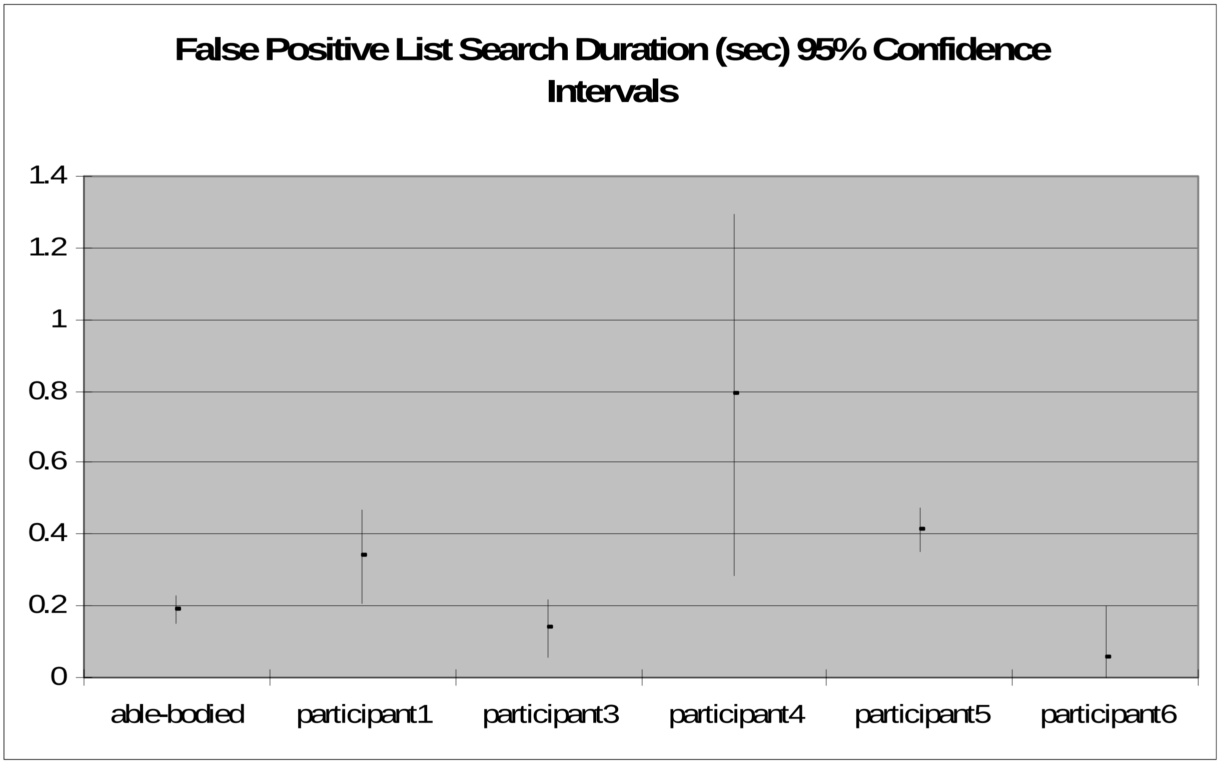


Figure 25. False positive list search time 95% confidence intervals

7.2.2.3 Successful Anticipation

Successful anticipation occurred when the participant correctly predicted whether the target word was in the list or not. It was calculated as the sum of positive and negative searches divided by the total number of searches.

Successful anticipation = (positive searches + negative searches) / (positive searches + negative searches + false positive searches + false negative searches)

Table 12 contains the average successful anticipation for each block of five trials for each of the able-bodied participants.

Table 12. Average successful anticipation on a per block basis

	block1	block2	block3	block4	block5	block6	block7	block8	block9	block10
A	.552	.665	.584	.505	.642	.716	.691	.664	.643	.670
B	.600	.644	.591	.744	.655	.600	.608	.473	.612	.656
C	.496	.592	.407	.469	.527	.663	.460	.544	.493	.671
D	.572	.590	.568	.497	.522	.666	.524	.590	.482	.612
E	.503	.599	.565	.637	.655	.628	.636	.697	.663	.636

A one-way repeated-measures ANOVA was performed at $\alpha = 0.05$ to determine if block order had a significant effect on successful anticipation. Results showed $p = 0.079$, indicating no relationship between block order and successful anticipation.

Figure 26 shows the 95% confidence intervals for successful anticipation.

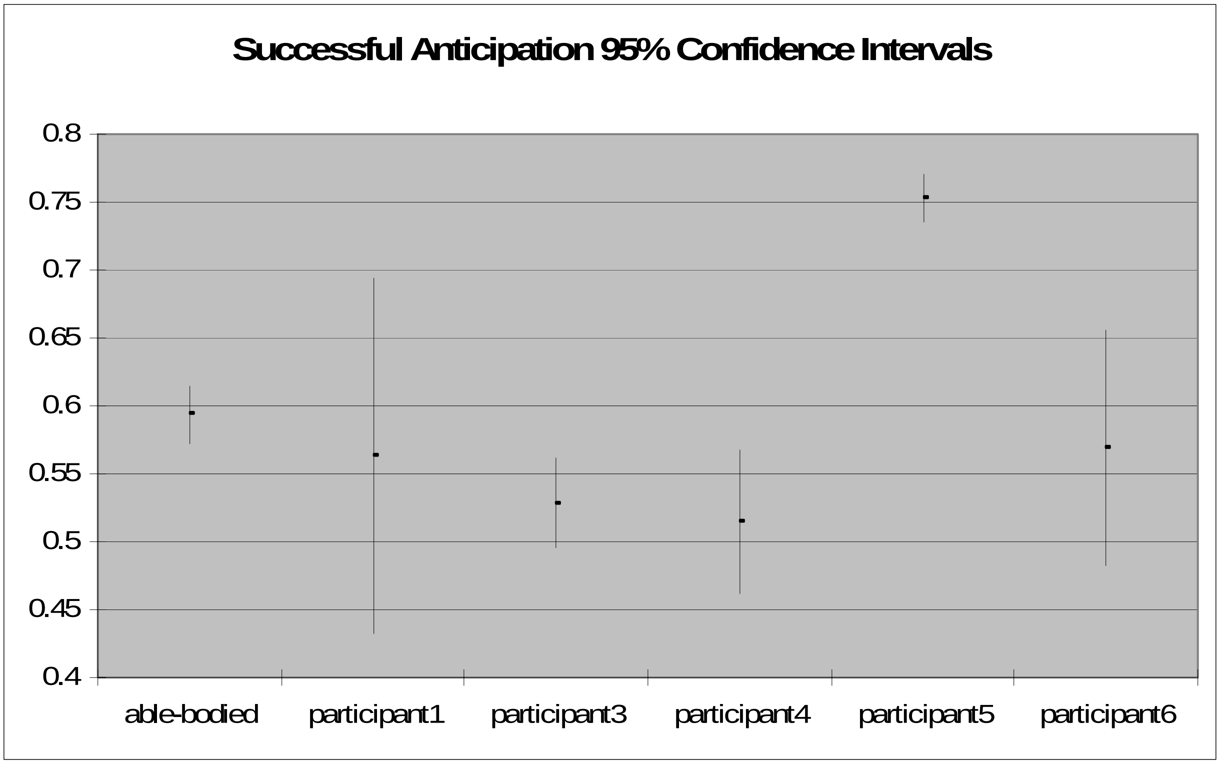


Figure 26. Successful anticipation 95% confidence intervals

7.2.2.4 Successful Searches

Successful searches occurred when the participant selected the target word from the list during a search when the target word was displayed in the list. Figure 27 shows the 95% confidence intervals for the duration of a successful list search which is measured in seconds.

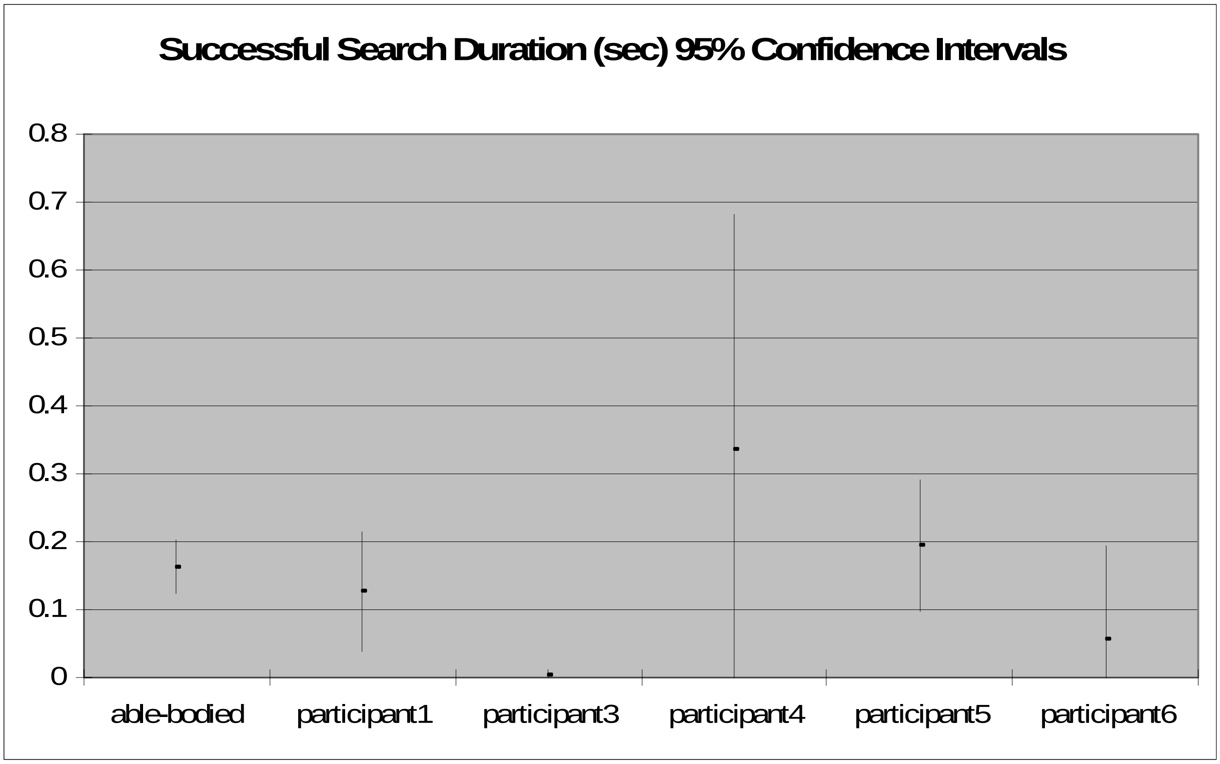


Figure 27. Successful list search time 95% confidence intervals

7.2.2.5 Unsuccessful Searches

Unsuccessful searches occurred when the participant did not select the target word from the list during a search when the target word was displayed in the list. Figure 28 shows the 95% confidence intervals for the duration of an unsuccessful list search which is measured in seconds.

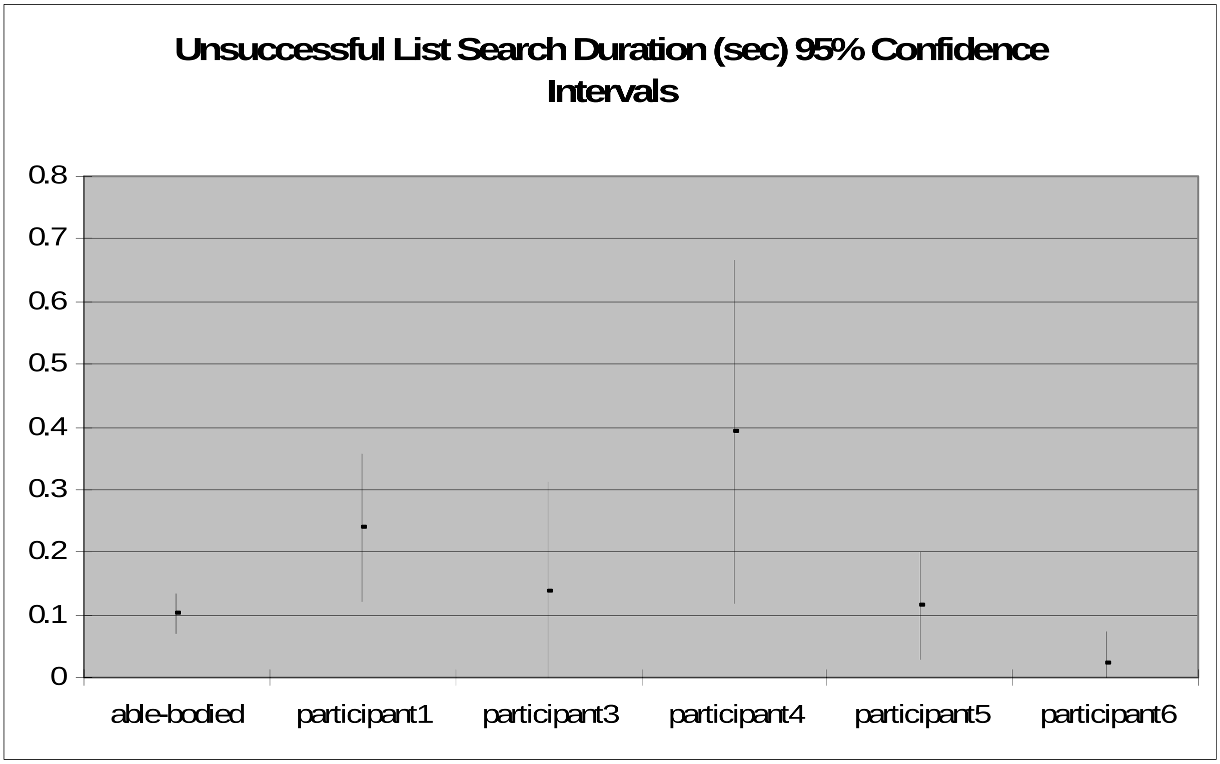


Figure 28. Unsuccessful list search time 95% confidence intervals

7.2.2.6 List Search Duration

Table 13 contains the average list search duration in seconds for each block of five trials for each of the able-bodied participants.

Table 13. Average list search duration (sec) on a per block basis

	block1	block2	block3	block4	block5	block6	block7	block8	block9	block10
A	.207	.148	.229	.206	.178	.164	.167	.227	.213	.157
B	.361	.135	.301	.107	.347	.244	.117	.249	.236	.239
C	0	.012	0	0	0	0	0	0	0	0
D	.277	.303	.258	.344	.002	.122	.146	0	.106	.137
E	.350	.410	.244	.213	.350	.352	.257	.276	.227	.318

A one-way repeated-measures ANOVA was performed at $\alpha = 0.05$ to determine if block order had a significant effect on list search duration. Results showed $p = 0.654$, indicating no relationship between block order and list search duration.

The average word prediction list search durations across search types were used to calculate 95% confidence intervals which are shown in Table 14 and Figure 29.

Table 14. Confidence intervals for list search duration (sec)

	to	from	average
able-bodied	0.214	0.144	0.179
participant1	0.342	0.161	0.252
participant3	0.126	0.066	0.0962
participant4	0.942	0.285	0.613
participant5	0.369	0.247	0.308
participant6	0.198	0	0.058

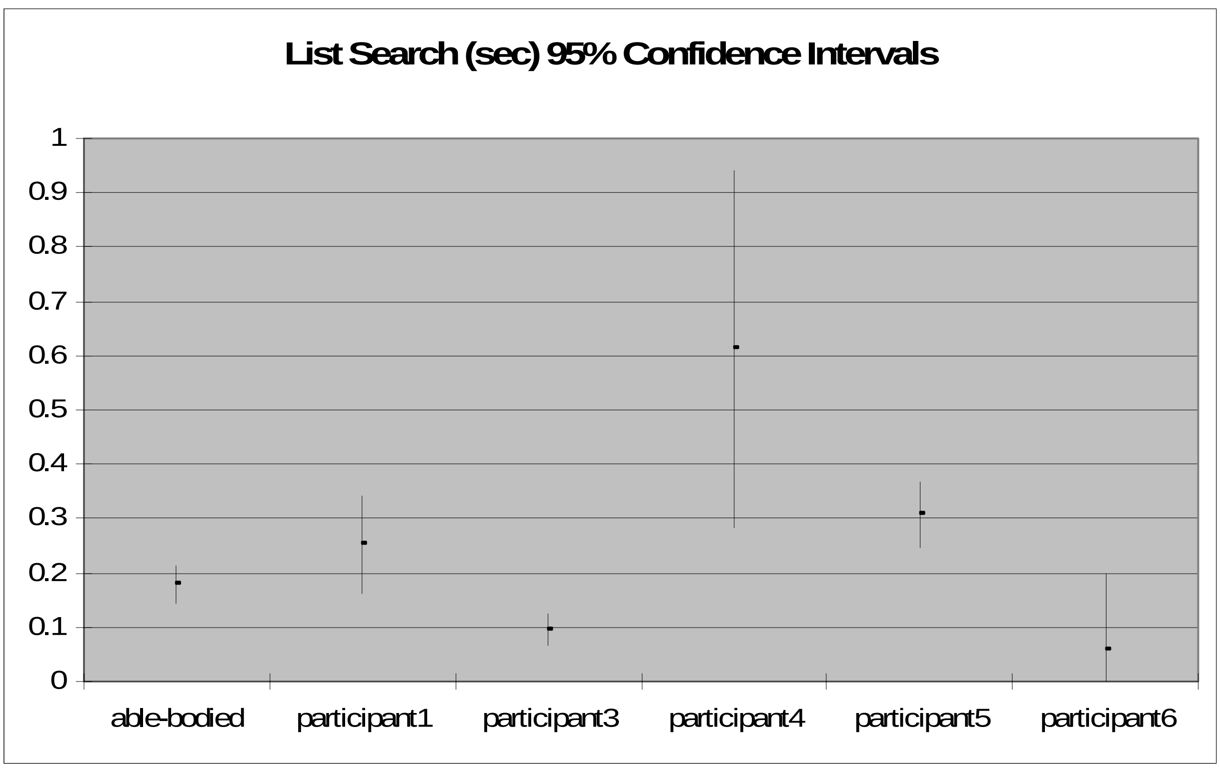


Figure 29. 95% confidence intervals for list search duration (sec)

7.3 VISUAL FIXATIONS

The number of fixations on the presented text, transcribed text, and on-screen keyboard were each tallied on a per sentence basis. The tallies were used to calculate the average number of fixations on a per block basis. An average was also calculated for the letters only and word prediction enhanced typing conditions.

7.3.1 Fixations on Presented Text

Figure 30 shows 95% confidence intervals for the number of fixations on the presented text for the letters only and word prediction typing conditions.

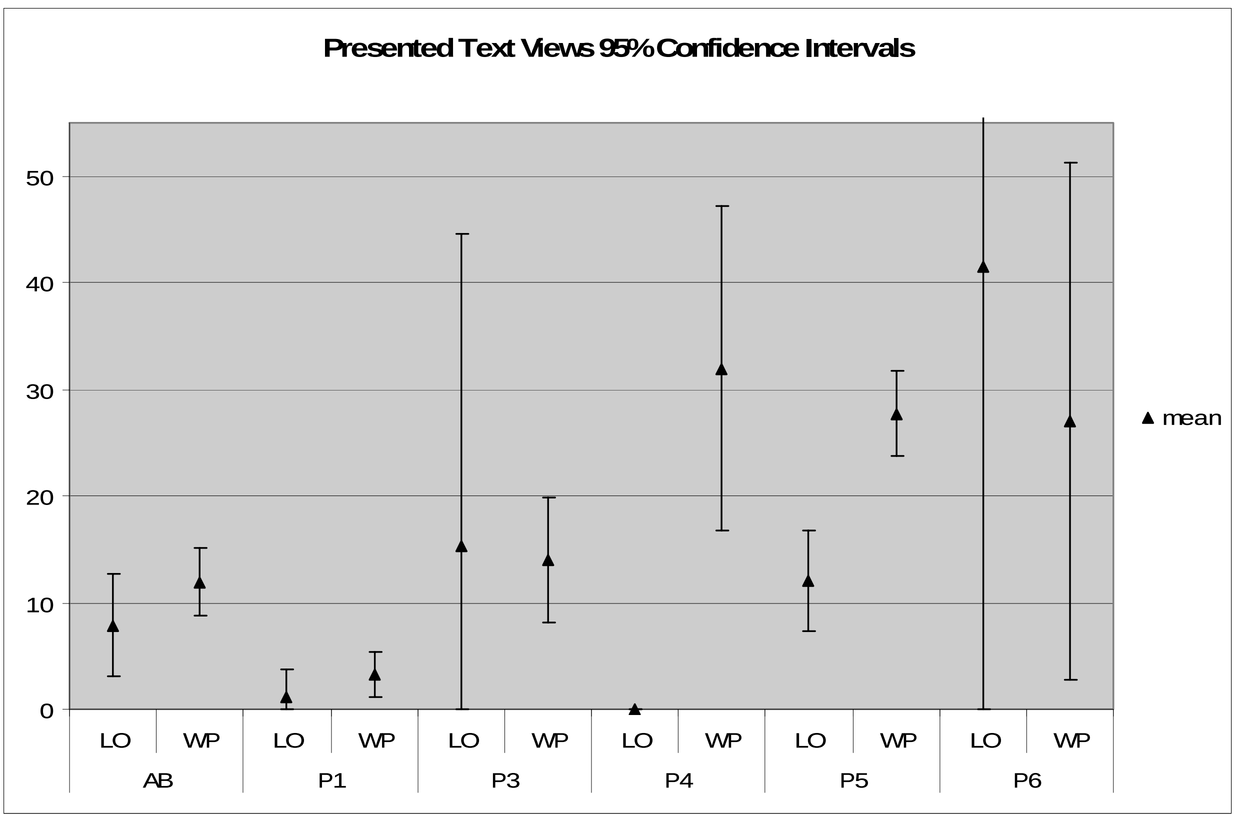


Figure 30. Fixations on presented text 95% confidence intervals

7.3.2 Fixations on Transcribed Text

Figure 31 shows 95% confidence intervals for the number of fixations on the transcribed text for the letters only and word prediction typing conditions.

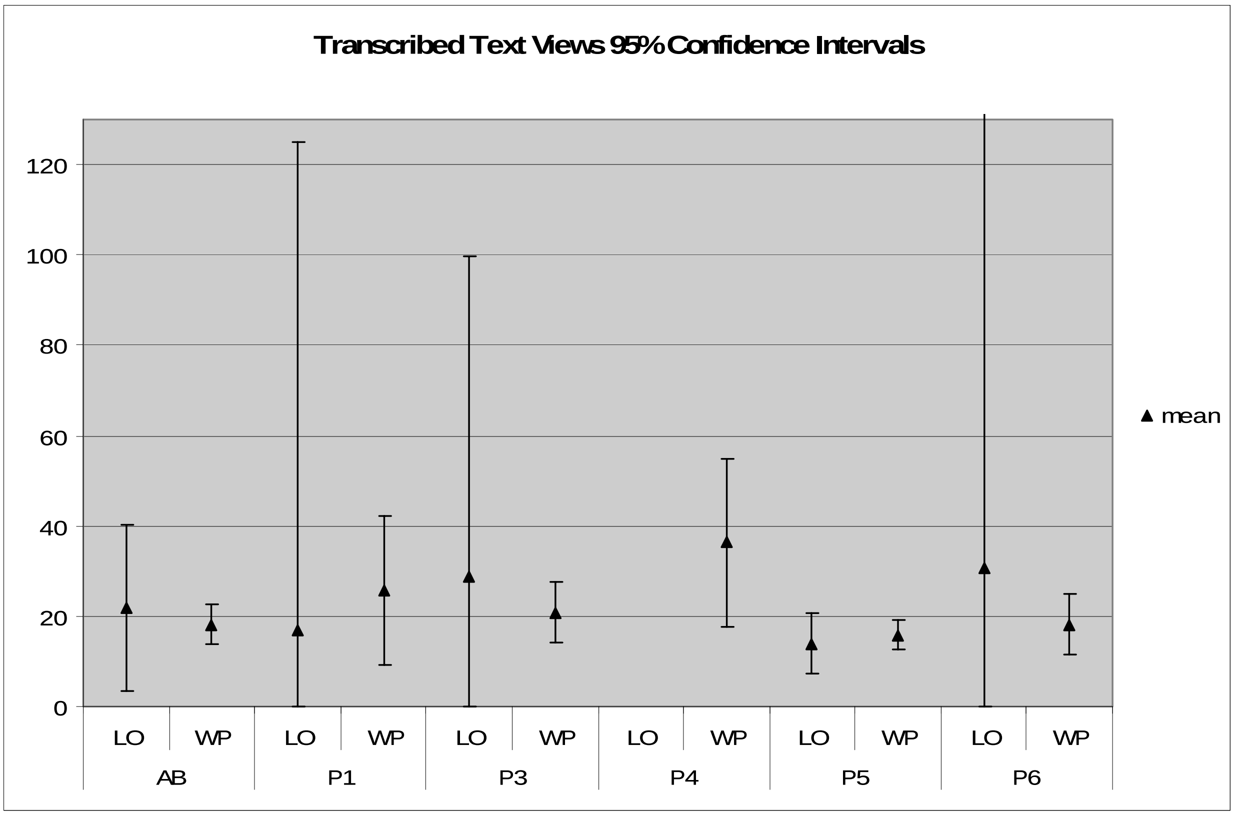


Figure 31. Fixations on transcribed text 95% confidence intervals

7.3.3 Fixations on On-Screen Keyboard

Figure 32 shows 95% confidence intervals for the number of fixations on the on-screen keyboard for the letters only and word prediction typing conditions.

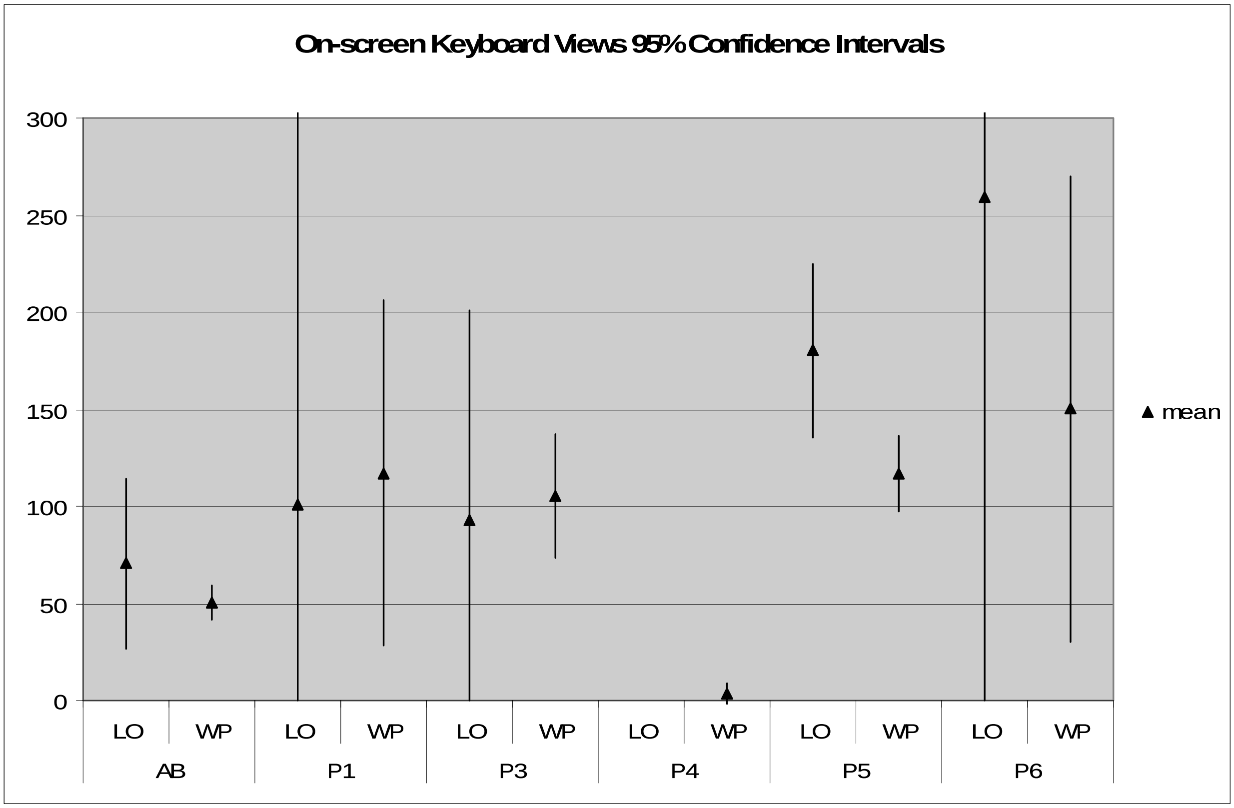


Figure 32. On-screen keyboard fixations 95% confidence intervals

7.4 VISUAL FIXATION SEQUENCES

7.4.1 Transitional Frequency Matrices

Data relative to sequences of fixations was used to calculate transitional frequency matrices for each keystroke type (FIX, WPSELECTION, LETTER, SPACE, TRANSITION). These matrices were computed using data for all occurrences of one-fixation and two-fixation sequences for each participant. Each element of the matrix contains the number of times the identified two-fixation sequence occurred. The row identifies the first fixation and the column identifies the second. Table 15 shows a sample transitional frequency matrix including data combined across all keystroke types. The label "outside" refers to fixations outside the defined areas of interest (i.e. a fixation somewhere other than the presented text, word prediction list, transcribed text, or on-screen keyboard). The column labeled "none" is for sequences consisting of a single fixation. Note that the diagonal is filled with zeros indicating the absence of the transition to self condition which is a common assumption in the coding and analysis of behavior sequences (26).

Table 15. Transitional frequency matrix (observed)

	presented	transcribed	wp list	keyboard	outside	none	f(first)
presented	0	12	35	127	30	212	416
transcribed	70	0	15	181	102	311	679
wp list	8	37	0	160	18	394	617
keyboard	74	143	104	0	171	1263	1755
outside	70	122	57	126	0	143	518
f(second)	222	314	211	594	321	2323	3985

Probability matrices corresponding to the transitional frequency matrices were computed by dividing each element by the total number of one and two fixation sequences which is located in element(f(second),f(first)). The probability matrix corresponding to Table 15 is shown in Table 16.

Table 16. Corresponding probability matrix

	presented	transcribed	wp list	keyboard	outside	none
presented	0	0.003	0.009	0.032	0.008	0.053
transcribed	0.018	0	0.004	0.045	0.026	0.078
wp list	0.002	0.009	0	0.040	0.005	0.099
keyboard	0.019	0.036	0.026	0	0.044	0.317
outside	0.018	0.031	0.014	0.032	0	0.036

7.4.2 Number of Samples

An appropriate number of samples must be collected in order to assign significance to computed z-scores. The following equation, adopted by Bakeman and Gottman (26), provides an estimate of the number of data points required for significance.

N = 9 / [P(1-P)] where N is the minimum number of sequences required and P is the expected probability of the least frequent sequence. The zero order model which assumes that all codes occur with equal probability is used to provide the expected probability of the least frequent sequence. Given no transition to self condition, the probability for any element is 1/25 = .04. This results in the following.

N = 9/[.04(1-.04)] = 234

Considering that 234 data points must be collected in order for the z-score to be significant, the z-scores cannot be compared across keystroke types. Table 17 shows the number of samples collected for each keystroke type for each participant. Types with enough data to be tested for significance appear in bold.

Table 17. N collected for each keystroke type for each participant

participant	all	fix	wp selection	letter	space	transition
a	**3985**	193	**637**	**2667**	**427**	61
b	**3799**	103	**728**	**2373**	**492**	103
1	**3632**	111	**582**	**2430**	**431**	78
2	**750**	15	163	**512**	47	13
c	**5882**	101	4	**4445**	**1170**	162
3	**4323**	213	230	**3161**	**655**	64
d	**6088**	**249**	137	**4334**	**1139**	229
4	**2982**	129	**391**	**1808**	**592**	62
e	**7542**	117	**2344**	**4421**	**497**	163
5	**7988**	167	**1443**	**5151**	**1008**	219
6	**5240**	**438**	**239**	**3486**	**986**	91

7.4.3 Analysis

Data provided in the event sequence probability matrices was evaluated to determine significance. The question is whether the observed transitional frequencies and corresponding probabilities occurred by chance or if sequences of behavior are truly indicated by the collected data.

This analysis was based on discussion and instructions provided by Bakeman and Gottman (26). To determine significance observed data is compared to expected data typically provided by zero or first order models. A zero-order model assumes that all elements in the matrix occur with equal probability. A first-order model uses the number of occurrences of each fixation but assumes random ordering, i.e. the probability of a given sequence occurring is simply the product of the probabilities for the composite individual fixations. Table 18 and Table 19 contain the frequencies and corresponding probabilities for the transitional frequency matrix in Table 15.

Table 18. Frequency

	first	second
presented	416	222
transcribed	679	314
wp list	617	211
keyboard	1755	594
outside	518	321
none	0	2323
total	3985	3985

Table 19. Probability

	first	second
presented	0.104	0.056
transcribed	0.170	0.079
wp list	0.155	0.053
keyboard	0.440	0.149
outside	0.130	0.081
none	0	0.583
total	1	1

The first order model corresponding to the data in Table 19 is shown in Table 20.

Table 20. First order model

	probability (second)	0.056	0.079	0.053	0.149	0.081	0.583
probability (first)		presented	transcribed	wp list	keyboard	outside	none
0.104	presented	0.006	0.008	0.006	0.016	0.008	0.061
0.170	transcribed	0.009	0.013	0.009	0.025	0.014	0.099
0.155	wp list	0.009	0.012	0.008	0.023	0.012	0.090
0.440	keyboard	0.025	0.035	0.023	0.066	0.035	0.257
0.130	outside	0.007	0.010	0.007	0.019	0.010	0.076
0	none	0	0	0	0	0	0

Given that transition to self does not occur, the first order model can be modified to include some information concerning the ordering of transitions. The diagonal is filled with zeros as in the observed data and the probability of the second fixation occurring is no longer simply the frequency divided by the total number of sequences. Instead the frequency is divided by the total number of sequences minus the frequency of the first fixation.

$$p(second) = f(second)/(N-f(first))$$

The adjusted model is shown in Table 21.

Table 21. Adjusted first order model probabilities

	presented	transcribed	wp list	keyboard	outside	none
presented	0	0.009	0.006	0.016	0.009	0.064
transcribed	0.010	0	0.010	0.028	0.015	0.108
wp list	0.009	0.013	0	0.024	0.013	0.095
keyboard	0.029	0.041	0.027	0	0.042	0.302
outside	0.008	0.011	0.007	0.021	0	0.082

The corresponding frequency matrix is shown in Table 22.

Table 22. Adjusted first order model frequencies

	presented	transcribed	wp list	keyboard	outside	none
presented	0	34.713	23.326	65.667	35.487	256.808
transcribed	41.062	0	39.027	109.868	59.373	429.670
wp list	36.294	51.335	0	97.111	52.479	379.780
keyboard	114.895	162.510	109.202	0	166.132	1202.260
outside	31.385	44.392	29.830	83.977	0	328.415

The frequencies predicted by the adjusted first order model were then compared with the actual observed frequencies (Table 15) with a z-score binomial test. The resulting z-score matrix appears in Table 23.

Table 23. Z-score matrix

	presented	transcribed	wp list	keyboard	outside	none
presented	0	-3.872	2.424	7.632	-0.925	-2.891
transcribed	4.539	0	-3.865	6.882	5.574	-6.061
wp list	-4.718	-2.014	0	6.461	-4.791	0.767
keyboard	-3.871	-1.563	-0.505	0	0.386	2.096
outside	6.920	11.714	4.993	4.635	0	-10.681

The z-scores in the matrix were examined for significance. Assuming $\alpha = .05$, a Bonferroni correction was applied to adjust alpha based on the number of tests performed. Applying the equation, $\alpha = \alpha$/number of tests, where the number of tests = 6x25 (6 z-score matrices with 25 z-scores to test in each), leads to $\alpha = .05/150$. A two-tailed test requires division by 2, thus $\boldsymbol{\alpha = .000167}$. For a normal curve the area under the body and the tail sum to one; alpha is the area under the tail or the area above z. Using Table A.1 in Portney and Watkins (22), which provides areas under the normal curve, an alpha of .000167 corresponds to a z value of 3.60. This means that z-scores greater than 3.60 (or less than -3.60) are considered significant in the sense that they are unlikely to occur. Table 24 shows the z-score matrix from Table 23 with significant scores in bold. Appendix N contains the z-score matrices for all of the participants with significant scores in bold.

Table 24. Z-score matrix with significant scores in bold

	presented	transcribed	wp list	keyboard	outside	none
presented	0	**-3.872**	2.424	**7.632**	-0.925	-2.891
transcribed	**4.539**	0	**-3.865**	**6.882**	**5.574**	**-6.061**
wp list	**-4.718**	-2.014	0	**6.461**	**-4.791**	0.767
keyboard	**-3.871**	-1.563	-0.505	0	0.386	2.096
outside	**6.920**	**11.714**	**4.993**	**4.635**	0	**-10.681**

7.4.4 Consistency

7.4.4.1 Within Subject/Within Keystroke Type

Data from each participant was partitioned into four groups based on the order in which sentence blocks were transcribed. The most probable sequences of fixations for each keystroke type were identified for each quarter of the testing and bar charts were created for visual comparison. The bar charts appear in Appendix O. An example is shown in Figure 33.

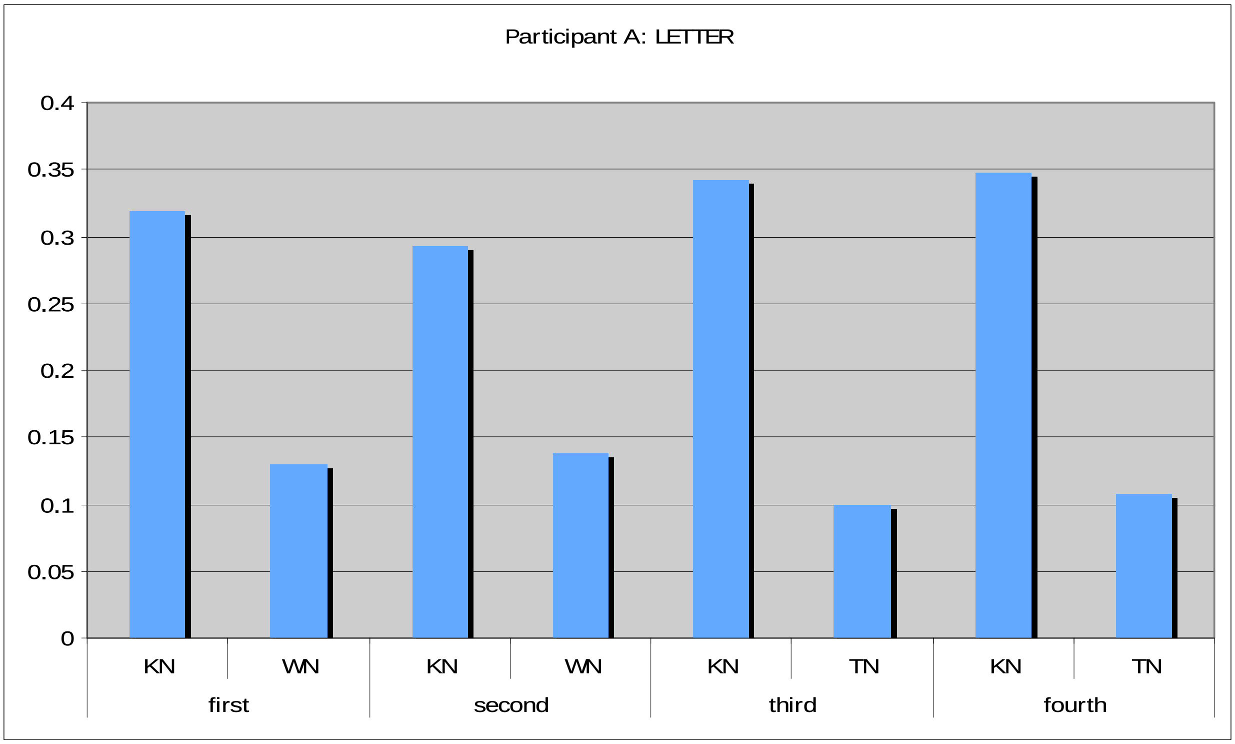


Figure 33. Bar chart examining within subject within keystroke type consistency

7.4.4.2 Within Subject/Across Keystroke Types

Data for each participant was examined over the entire test session to identify the most probable sequences of fixations for each keystroke type. The bar charts in Appendix P were created for visual comparison. An example is shown in Figure 34.

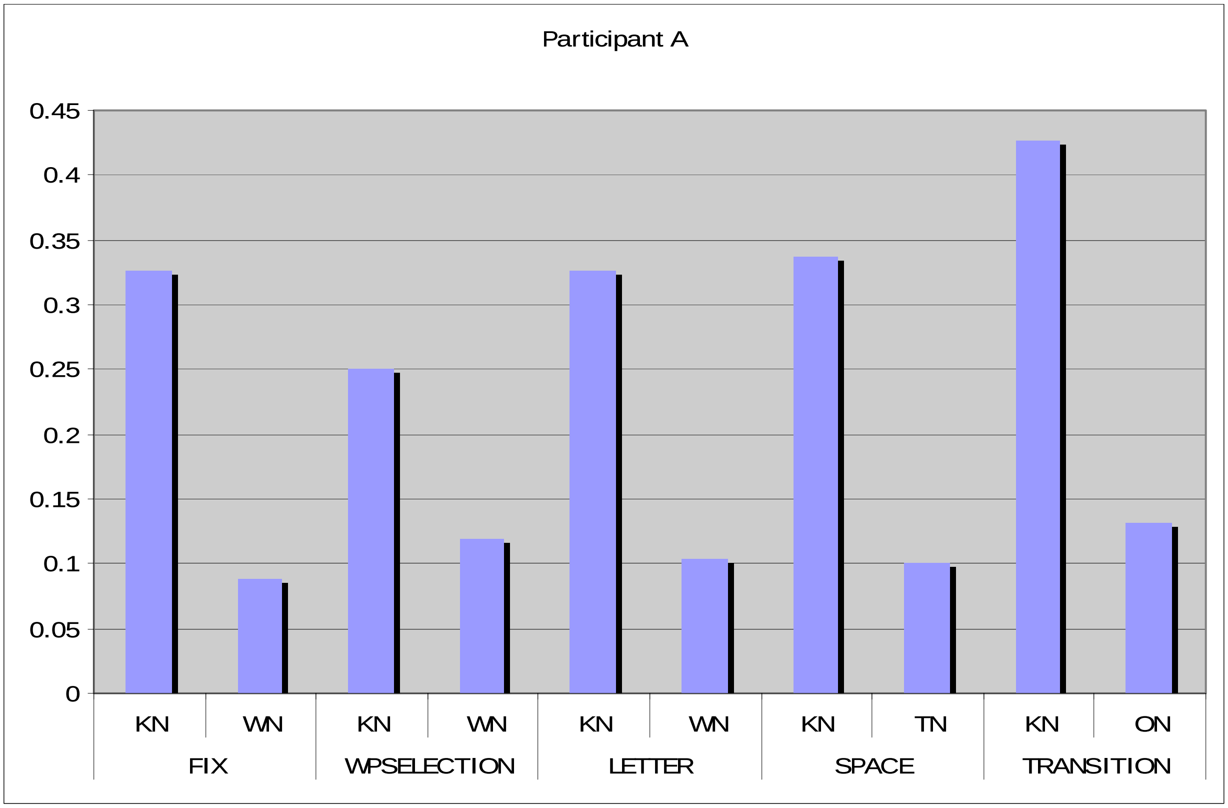


Figure 34. Bar chart examining within subject across keystroke types consistency

7.4.4.3 Across Subjects/Within Keystroke Type

Returning to the observed probability matrices for each event type on a per subject basis, the most highly probable sequences of fixations were identified. Bar charts were created for each keystroke type to compare the most probable sequences across subjects.

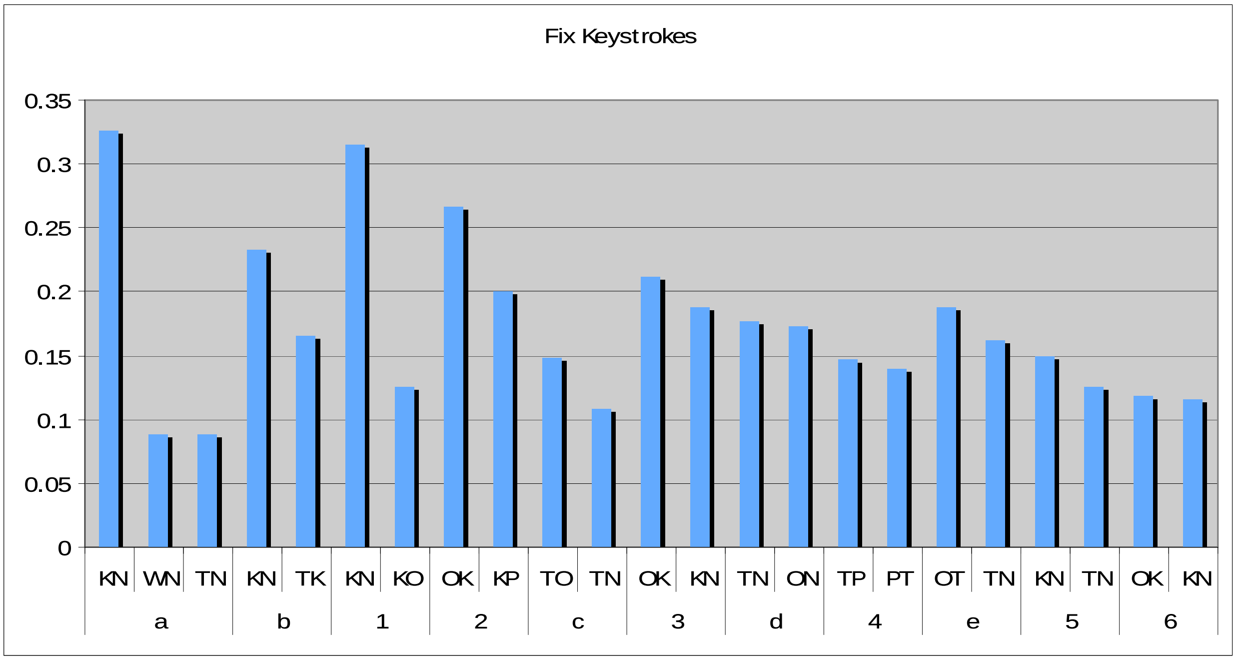


Figure 35. Most probable sequences for FIX keystrokes

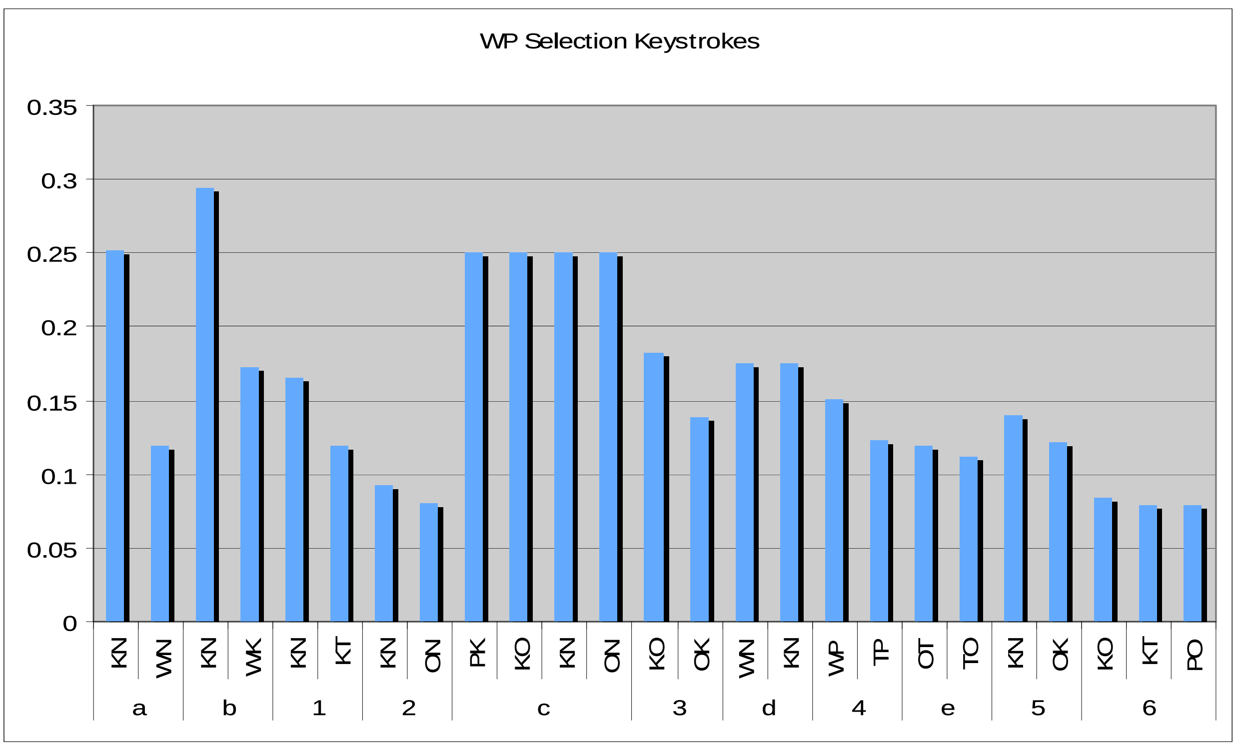


Figure 36. Most probable sequences for WPSELECTION keystrokes

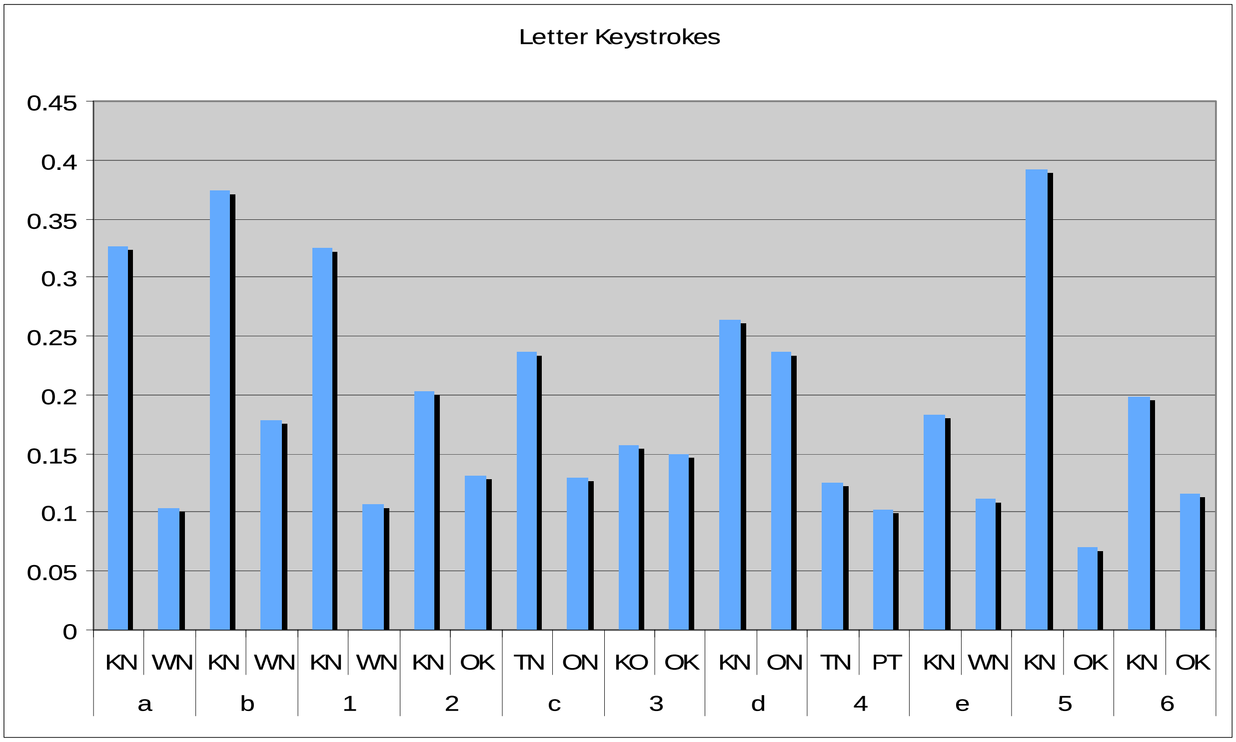


Figure 37. Most probable sequences for LETTER keystrokes

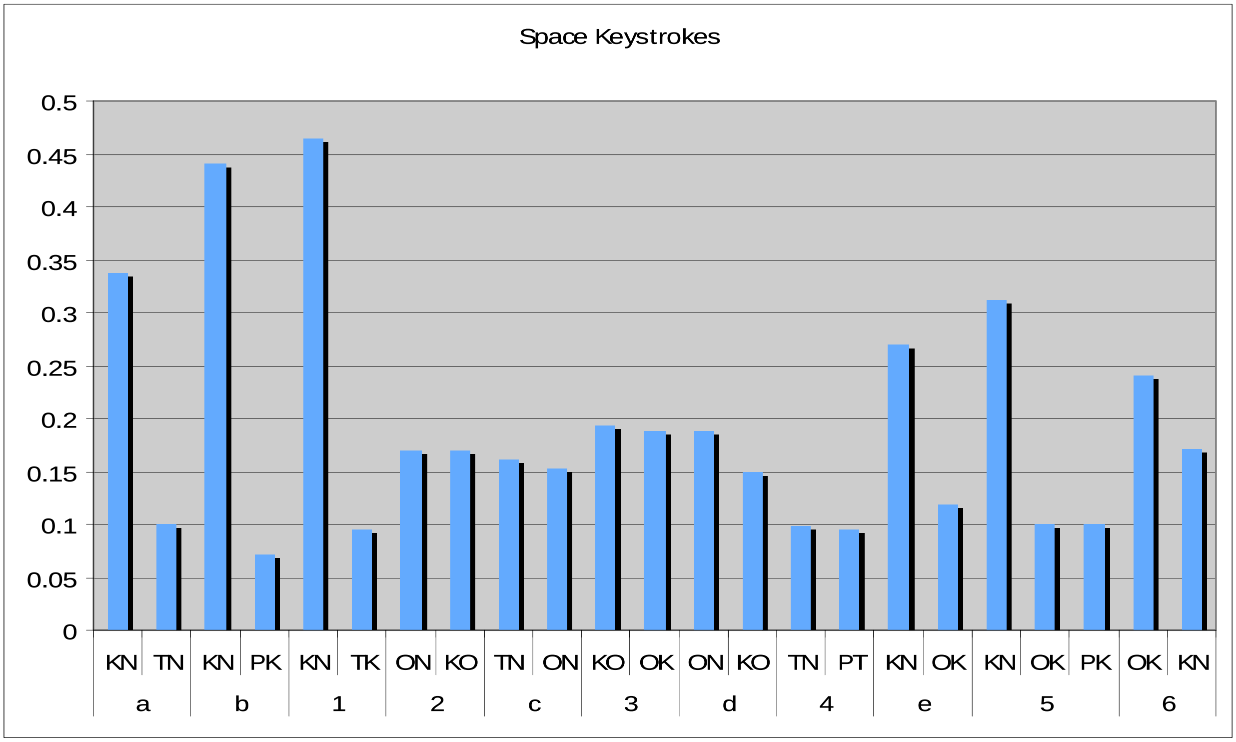


Figure 38. Most probable sequences for SPACE keystrokes

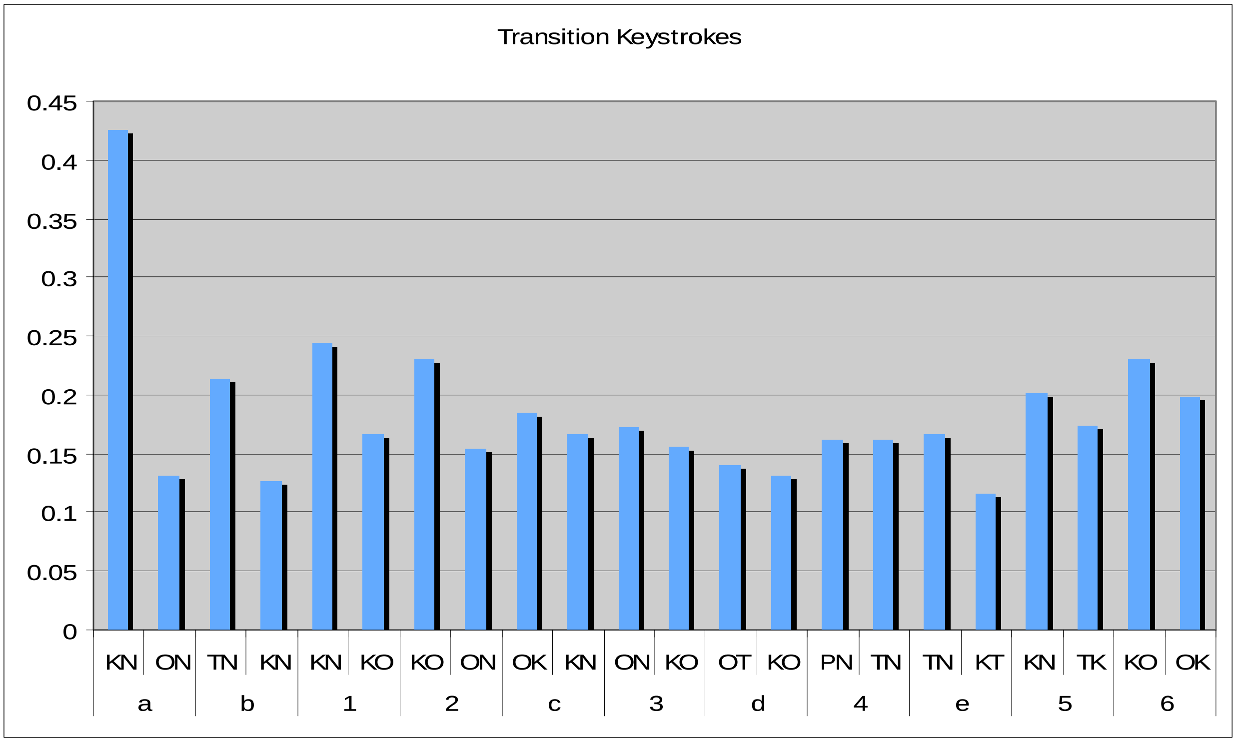


Figure 39. Most probable sequences for TRANSITION keystrokes

7.4.4.4 Across Subjects/Across Keystroke Types

Data for all of the able-bodied participants was combined and the most probable sequences were identified for each keystroke type. Figure 40 shows the identified sequences for each keystroke type.

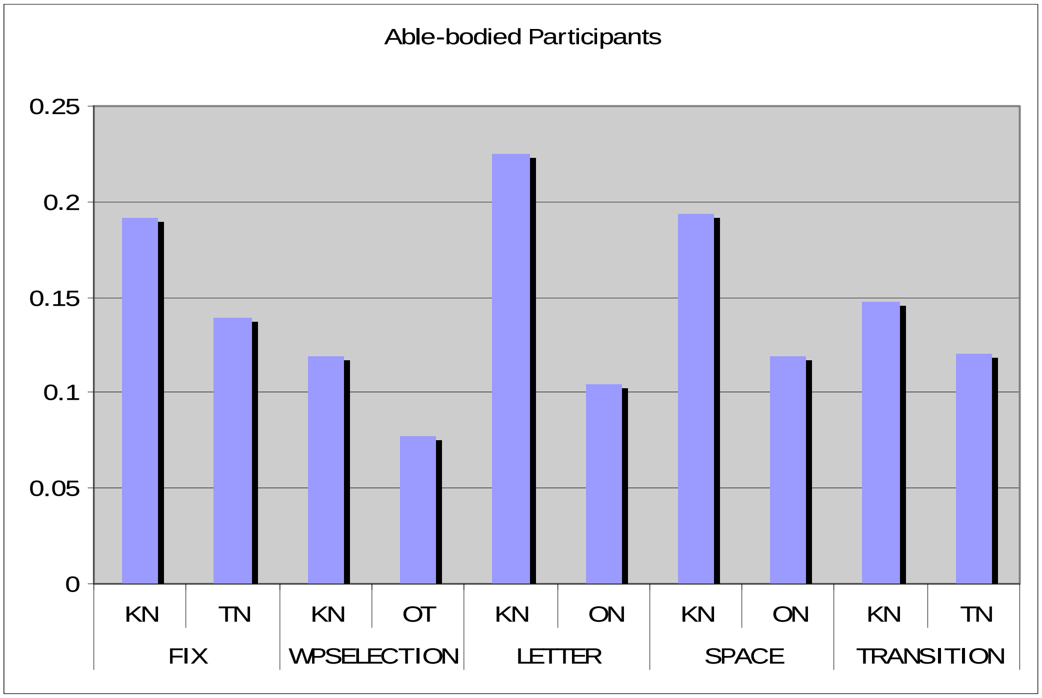


Figure 40. Most probable sequences across able-bodied participants

Confidence intervals for the probabilities of the two most frequently used sequences were computed across subjects to check for consistency across keystroke event type.

Table 25. Probability confidence intervals for sequence keyboard to none

k->n	to	from	average
all	0.281	0.130	0.205
fix	0.226	0.090	0.158
wpselection	0.204	0.072	0.138
letter	0.309	0.146	0.227
space	0.328	0.129	0.228
transition	0.219	0.059	0.139

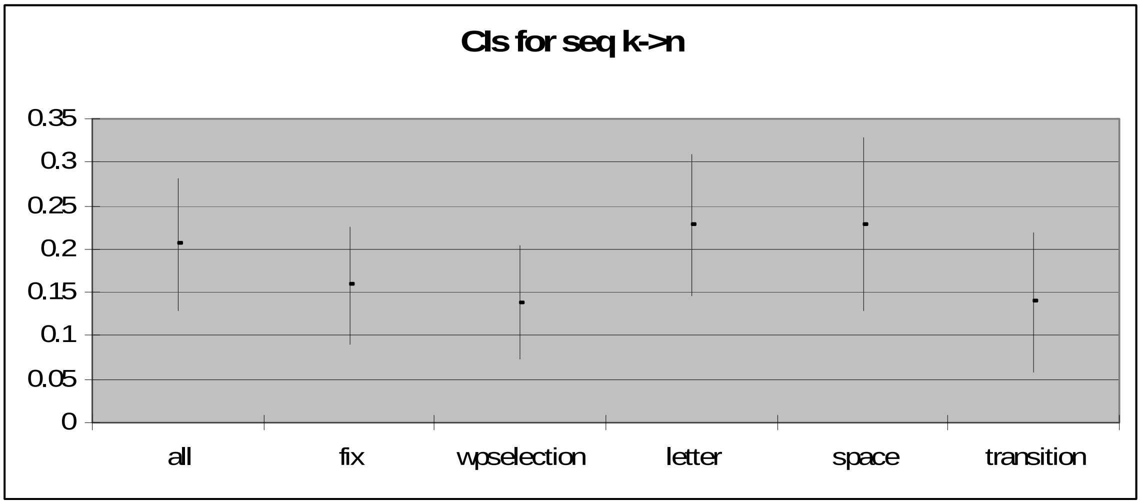


Figure 41. Probability confidence intervals for sequence keyboard to none

Table 26. Probability confidence intervals for sequence keyboard to outside

k->o	to	from	average
all	0.115	0.052	0.084
fix	0.112	0.051	0.082
wpselection	0.134	0.038	0.086
letter	0.113	0.049	0.081
space	0.142	0.065	0.104
transition	0.166	0.062	0.114

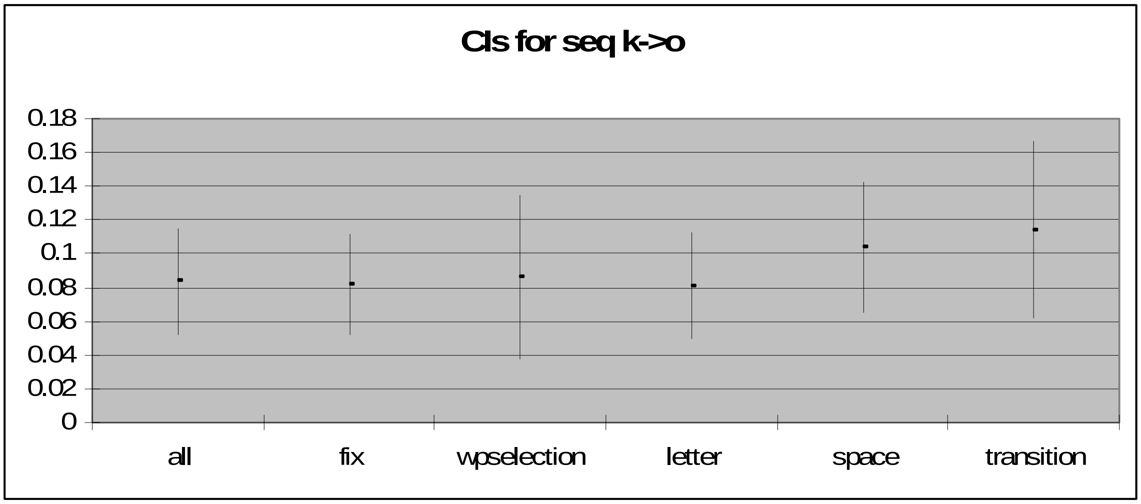


Figure 42. Probability confidence intervals for sequence keyboard to outside

8.0 DISCUSSION

8.1 RESEARCH QUESTION 1: EVENT SEQUENCES

8.1.1 Significance

As shown in Table 17, the number of data points collected varied among participants and key stroke type. This was due in part to the number of trials completed by the participants, but a larger influence was the style of interaction adopted by the user. The number of data points is actually the number of one and two fixation sequences the participant performed. The z-score matrices in Appendix N contain data with all key stroke event types combined for each participant as all of the participants had the required number of data points to support assignment of significance to z-scores under this condition. Examination of the matrices shows that all of the participants had significant z-scores indicating the presence of strategies or sequences of behaviors. Participant 2 had less data than the other participants, having only completed a single block of trials. The other participants had anywhere from 7 to 16 significant z-scores in their matrices.

8.1.2 Consistency

As consistency is being examined with the ultimate goal of determining the feasibility of creating models based on the collected data, it is useful to frame the discussion around levels of consistency. Table 27 shows a matrix of four elements with each element representing a combination of consistency within or across subjects and within or across keystroke type.

Table 27. Levels of consistency

	within keystroke type	across keystroke type
within subjects	Did individual subjects perform consistently when entering a single type of keystroke?	Did individual subjects perform consistently when entering all types of keystrokes?
across subjects	Did all subjects perform similarly when entering a single type of keystroke?	Did all subjects perform similarly when entering all type of keystrokes?

8.1.2.1 Within Subject/Within Keystroke Type

Participants showed variation in the sequences most frequently used with the degree of variation depending on the individual. For example, Participant 5 showed variation in sequences selected over each quarter.

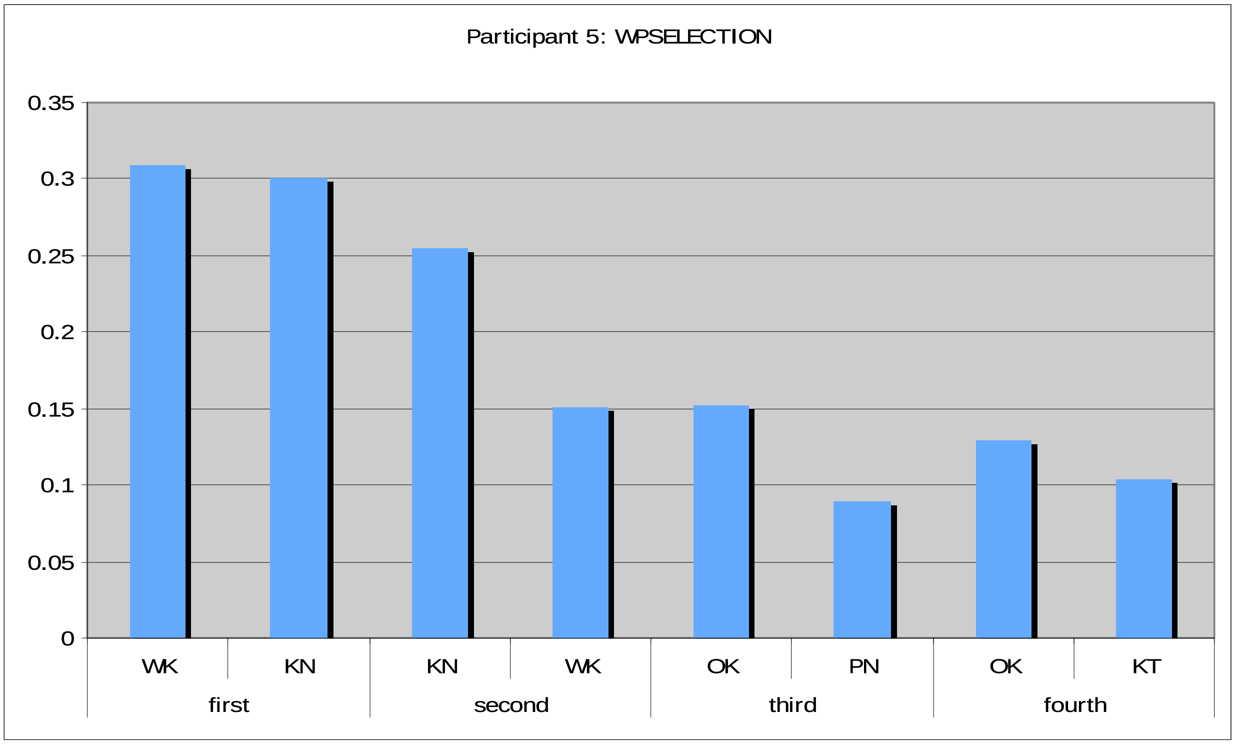


Figure 43. Participant 5 probabilities for most frequently used sequences for each quarter of the test session

At the other extreme, Participant D showed almost complete consistency in selection of sequences with minor differences between the probability of the first and second most frequently used sequences.

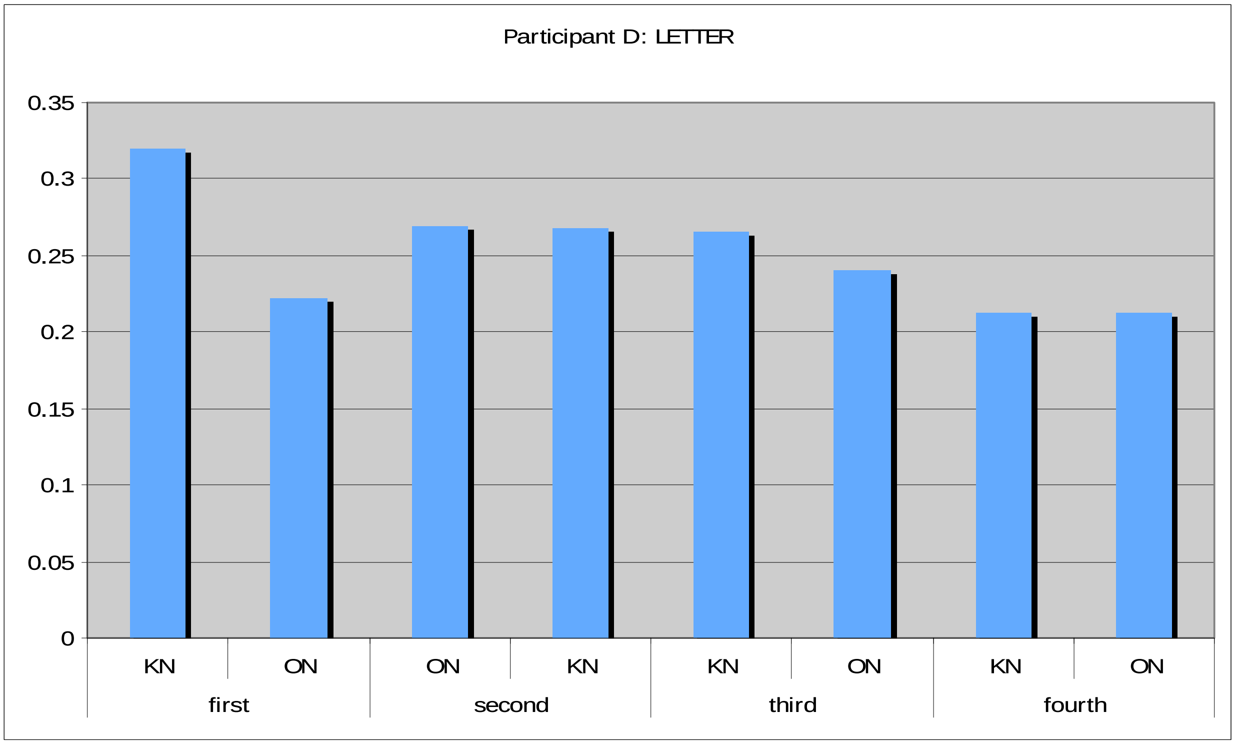


Figure 44. Participant D probabilities for most frequently used sequences for each quarter of the test session

Participant A showed consistency and strong preferences for a particular sequence which is highly conducive to modeling.

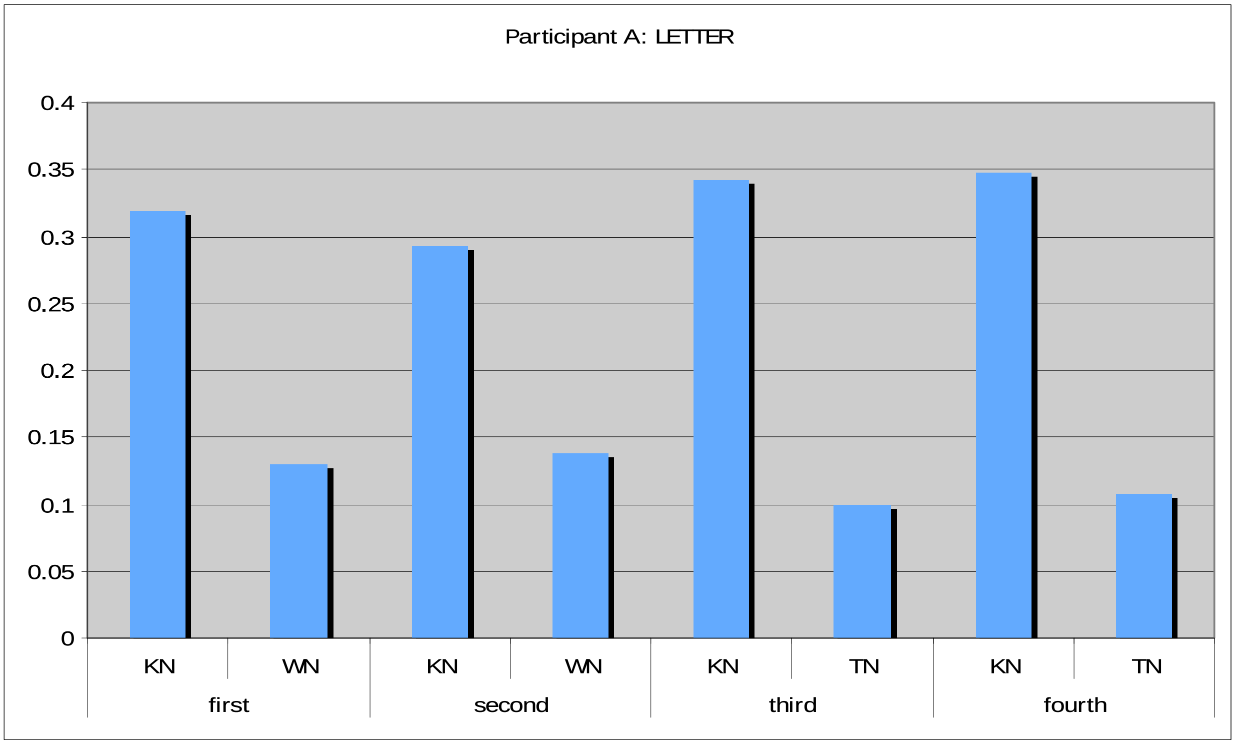


Figure 45. Participant A probabilities for most frequently used sequences for each quarter of the test session

8.1.2.2 Within Subject/Across Keystroke Types

Participants varied regarding consistency in their choice of sequences for each keystroke type. As shown in Figure 46, Participant A consistently showed a clear preference for the keyboard to none fixation sequence.

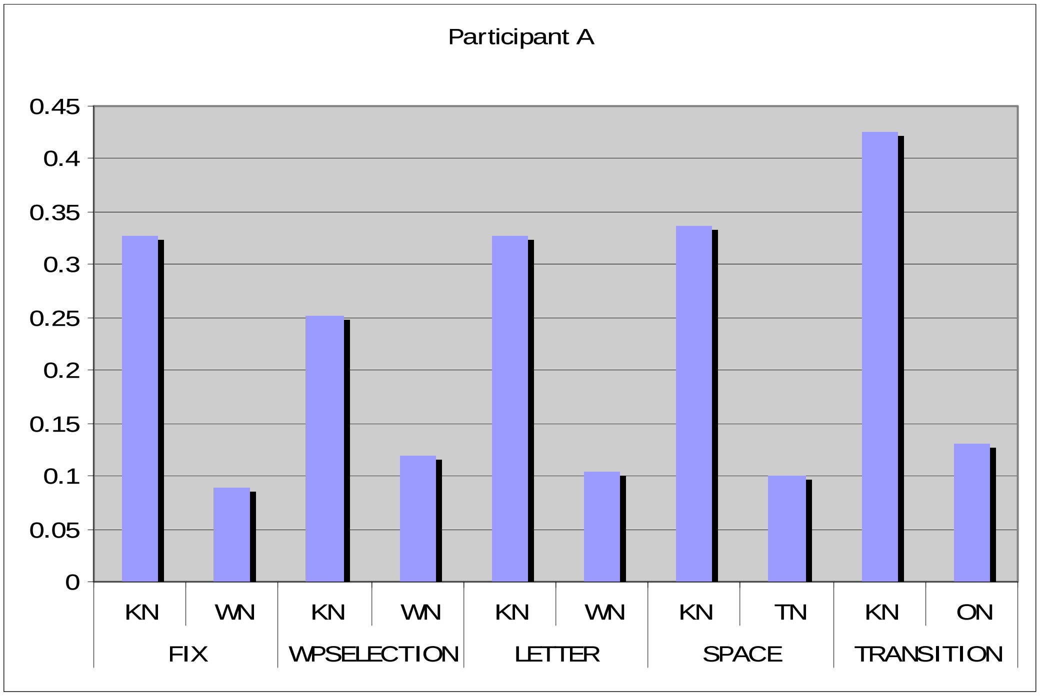


Figure 46. Participant A – most probable sequences for each keystroke type

In contrast, Participant D showed little consistency in sequence selection in addition to small differences in the probabilities of the first and second most likely sequences.

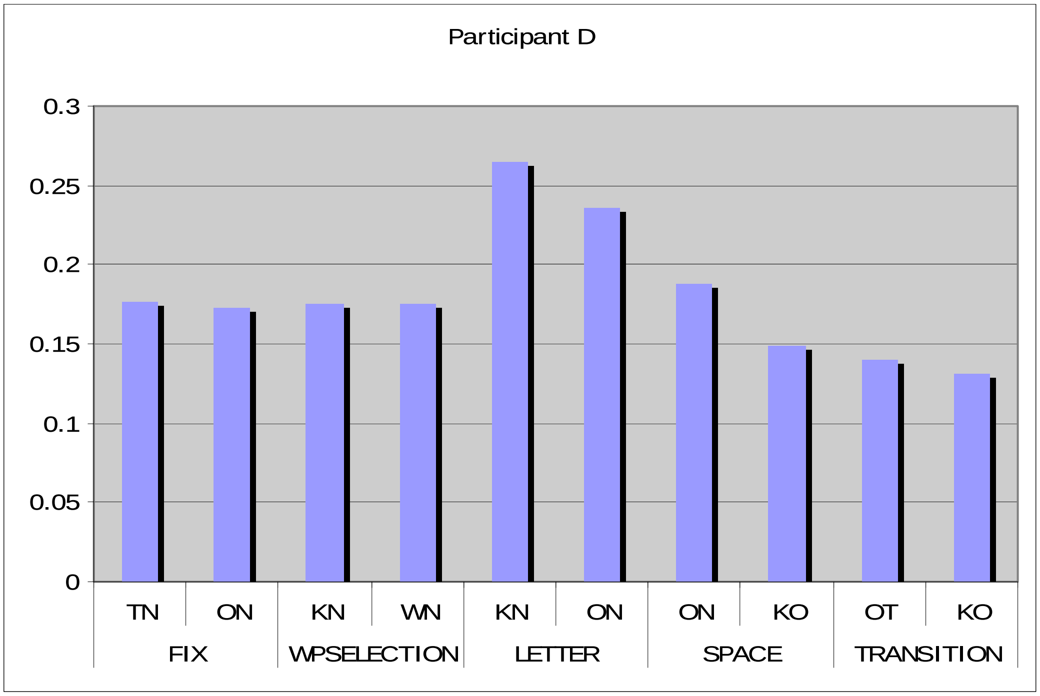


Figure 47. Participant D – most probable sequences for each keystroke type

As shown in Figure 48, Participant 5 performed between the two extremes.

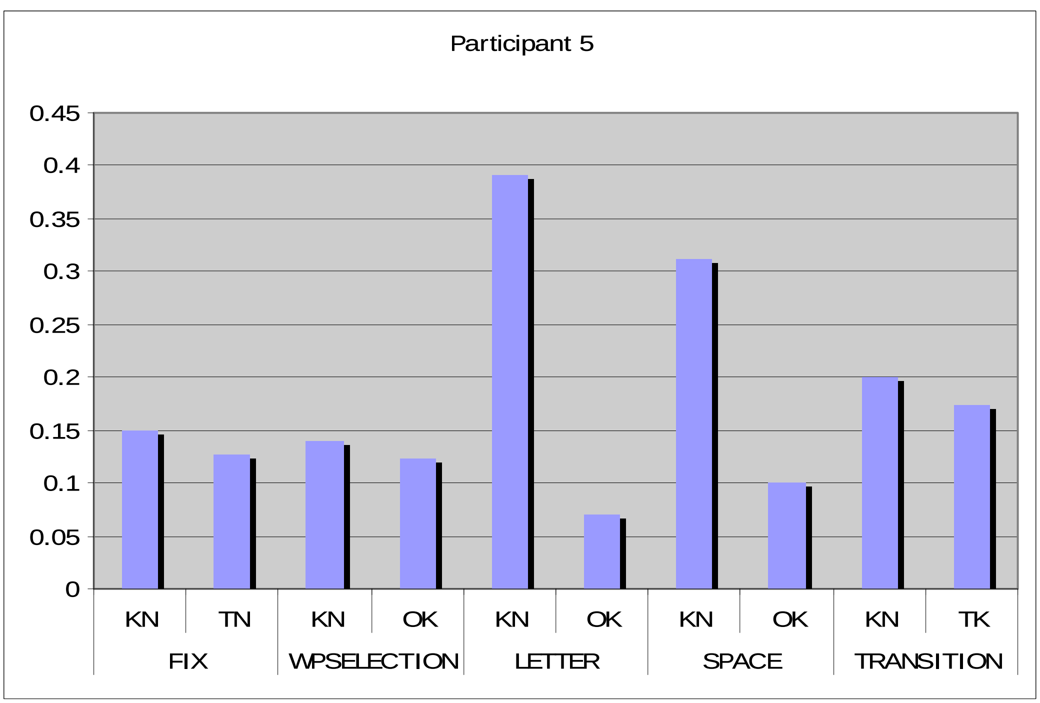


Figure 48. Participant 5 – most probable sequences for each keystroke type

8.1.2.3 Across Subjects/Within Keystroke Type

Variation was apparent in the most frequently used strategies for each keystroke type. Of particular interest is the chart showing event sequence probabilities for word prediction selection keystrokes. It was expected that highly probable sequences for this keystroke type would include fixations on the word prediction list but that was not the case. Further examination of the data relative to word prediction selection and fixations on the word prediction list shows that on average over 50% of the time when word prediction was used, a fixation on the word prediction list was not detected.

Table 28. Word prediction use without list fixation detected

participant	wp used	no search	% wp used without list search
A	276	150	54.3
B	273	124	45.4
1	140	77	55
2	47	31	66
C	2	2	100
3	39	35	89.7
D	47	10	21.3
4	65	23	35.4
E	379	45	11.9
5	370	169	45.7
6	28	14	50

One possible explanation is that participants may have searched the list when entering the previous character and located the word but for some reason waited to make the selection until the next character. Table 29 expands on the data in Table 28, providing the number of times the participant searched the list during entry of the character prior to the word prediction list selection. Also included is the number of times the target word appeared in the list when the participant performed the search. This data does not support the proposed explanation.

Table 29. List fixation during entry of character prior to wp selection

participant	list search prior	word in list during search	% missed wp list fixations explained
A	56	25	16.7
B	90	33	26.6
1	66	25	32.5
2	5	0	0
C	1	1	50
3	12	4	11.4
D	0	0	0
4	11	6	26.1
E	39	17	37.8
5	51	23	13.6
6	4	3	21.4

Other possible explanations for the data shown in Table 28 include errors related to data collection and list search times shorter than 40 milliseconds. Examination of the Morae recordings for selected trials performed by Participant 3 showed periods of time when the point of regard was lost. This was likely due to head movement and the time for the corresponding auto pan/tilt adjustment. In order to determine if there were shorter fixations on the word prediction list, one of the data files for Participant 3 was reloaded into the DQW application and a new fixation file was generated based on minimum fixation duration of 20 milliseconds. Figure 49 and Figure 50 show the old and new fixation files.

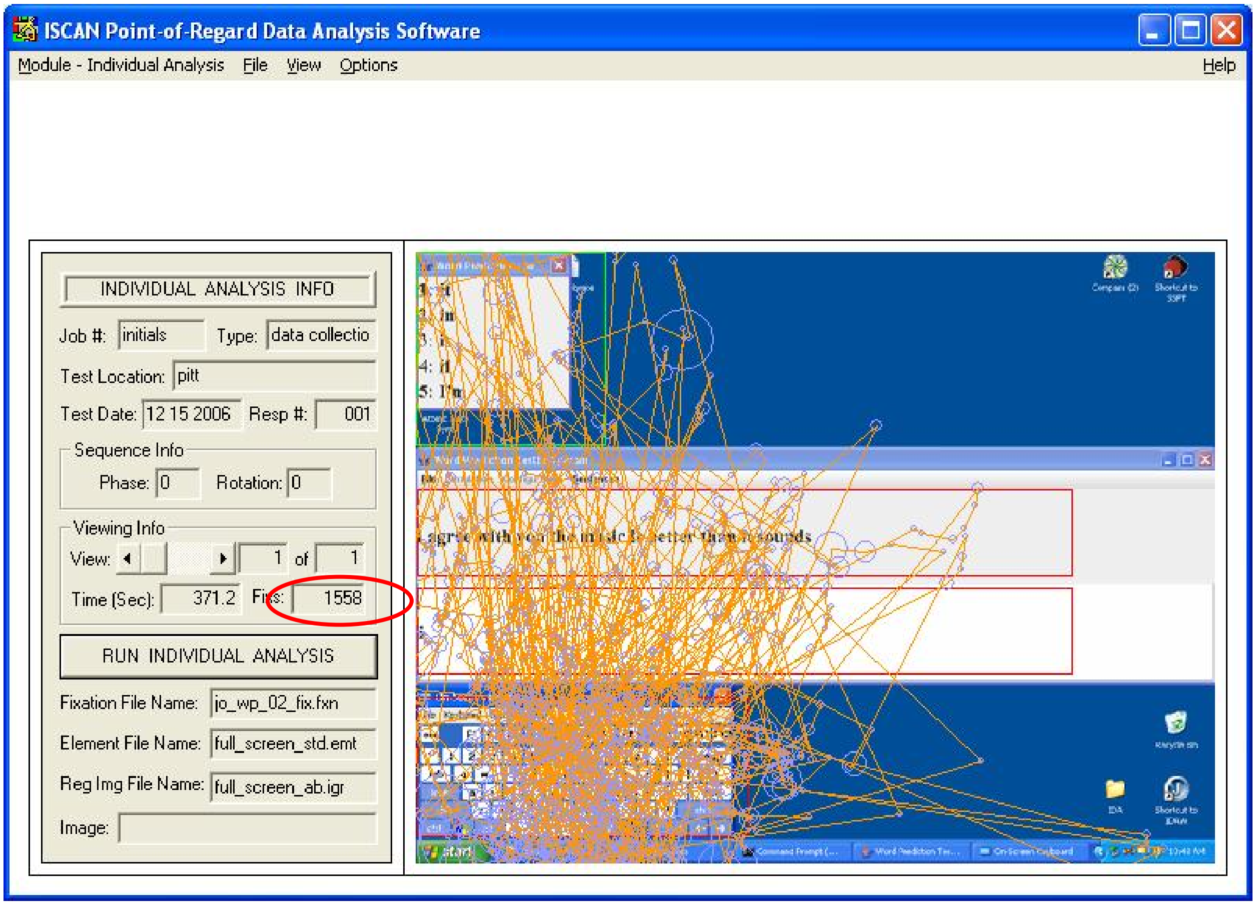


Figure 49. Fixations with minimum duration set to 40msec

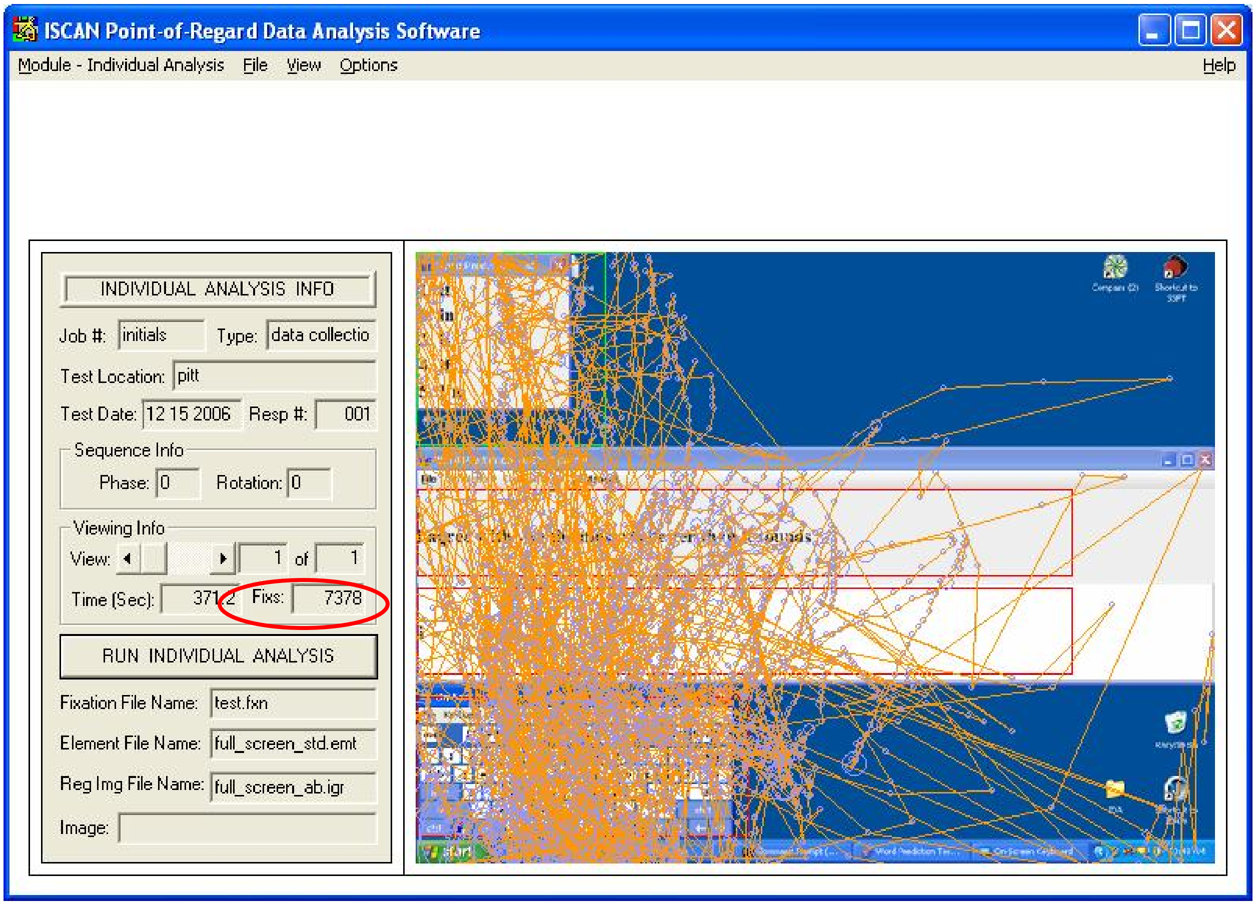


Figure 50. Fixations with minimum duration set to 20msec

The large increase in the number of fixations identified in and around the word prediction list supports the notion that the participant was performing a list search or possibly a pattern matching exercise rapidly. Additionally the fixations identified around the outside of the word prediction list indicate that possibly there were calibration issues adding to the number of missed fixations.

Identification of fixations with the ISCAN eye tracking system is based on a minimum time period in which the eye must remain fixed and specification of an allowed deviation. This deviation is the number of pixels the point of regard can move in the vertical and horizontal directions and still be considered “fixed”. Presumably this deviation is included to handle small movements of the eye such as the micro saccades which occur constantly. The maximum horizontal and vertical deviations were set to 5 and 3 pixels respectively. All of the settings related to the definition of fixations used in the experimental protocol were the defaults recommended by the engineers at ISCAN. The data from Participant 3 was reexamined with the horizontal and vertical deviations set to 20 pixels each. While fewer fixations were identified, the fixations were of longer duration. The likely explanation for this is the merging of fixations that were independent with the previous settings.

Eye tracking systems commonly identify fixations through either dwell time or velocity based approaches (28). The exact definition of what constitutes a fixation varies depending upon the eye tracking system used. Fixation durations are rarely under 100 milliseconds and are typically between 200 and 400 milliseconds (29). Eye movement is classified in terms of fixations, pursuits, and saccades. The test bench is not designed to illicit pursuit or tracking of a moving target; as such all data should be classified as saccades or fixations. Saccades are eye movements used to reposition the fovea. Little to no visual processing occurs during a saccade; the eye is essentially blind (28, 29). Given that fact, the point of regard data in the region of the word prediction list must indicate fixations on the list. There is simply no other reason for the fovea to be positioned in that manner and visual processing is dependent on fixations. This reasoning indicates that fixations occurred on the word prediction list and were not properly identified by the eye tracking software. The increase in fixations identified in the list region when the minimum fixation duration was reduced supports the notion that noise such as tiny flickers and micro saccades was not filtered and thus caused the fixation detection algorithm to miss or discard a number of fixations.

While it is difficult to draw conclusions without a clear definition of what should be considered a fixation on the word prediction list, based on the data it appears that in many cases participants were searching the list and fixations were not detected. Interestingly, the phenomena of word prediction selection without detection of a list fixation only occurred 11.9% of the time for participant E. This is considerably less than all of the other participants and fits with what would be expected. Qualitative observation during data collection indicated that participant E was one of the most careful and deliberate participants which could explain why the duration of her fixations on the word prediction list tended to be longer than the other participants.

8.1.2.4 Across Subjects/Across Keystroke Types

Overall, the most probable sequence was a fixation on the keyboard followed by a keystroke. This is reasonable given that the on-screen keyboard requires visual attention and a keystroke ends every event type. As expected based on the sources of error previously identified, data for Participant 4 did not follow the trends established by the other participants. Confidence intervals in Figure 41 and Figure 42 show no significant difference in the probabilities of the most common sequences across keystroke type as the intervals clearly overlap.

8.1.3 Summary

Returning to the questions posed in Table 27, trends in the data for individual participants varied to a wide degree making within subjects results inconclusive. Data across subjects showed slightly more promise given that a couple of sequences appeared to be favored by many of the participants and confidence intervals for those sequences were comparable across keystroke type. However, there was little consistency in selection of other highly probable sequences when considered across subjects. Variation existed to some degree in the most probable sequences of events performed by individuals and to a greater degree in the difference between the probabilities of the first and second most commonly performed sequences. This indicates the need for a modeling technique that supports a decision making process to identify the sequence to be performed in real time. The algorithm required to perform that decision making process was not clear based on the data, no clear guideline for sequence selection emerged.

8.2 RESEARCH QUESTION 2: EFFECT OF EXPERIENCE

There was an expectation that as participants gained experience using word prediction, they would learn to anticipate when a word appeared in the list and develop strategies of use leading to improvement in quantitative measures of performance. This was not the case with the data collected. Analysis showed that trial order had no significant effect on text entry rate, keystroke rate, successful anticipation, or word prediction list search duration. Results were likely influenced by the limited number of trials completed and fatigue. Testing occurred over a single two hour session which may not have provided the participants with enough practice using the system and may also have induced fatigue which could degrade performance.

8.3 RESEARCH QUESTION 3: PERFORMANCE DIFFERENCES

Table 30 provides a brief summary for each of the variables examined.

Table 30. Performance differences summary

Measure	WP	Letters
text entry rate	Y: AB higher	Y: AB higher
keystroke rate	Y: AB higher	Y: AB higher
keystroke savings compared to letters only	N	N
keystroke savings compared to optimal letters only	N	N
keystroke savings compared to optimal word prediction	N	N
total error rate	N	N
uncorrected error rate	N	N
corrected error rate	N	N
utilized bandwidth	N	N
wasted bandwidth	N	N
successful anticipation	N	N
successful list search time	N	N
unsuccessful list search time	N	N
positive list search time	N	N
false positive list search time	N	N
fixations on presented text	N	N
fixations on transcribed text	N	N
fixations on the on-screen keyboard	N	N

Text entry rate and keystroke rate were clearly higher for the able-bodied group under both letters only and word prediction enhanced typing conditions. This was expected as all of the participants with disabilities had some form of motor impairment affecting computer access. Participant 3 showed an extremely wide confidence interval for both rates during letters only typing. This participant had some difficulty positioning the trackball and made frequent adjustments throughout the trials.

All of the keystroke savings metrics show that the participants with disabilities performed on par with the able-bodied group. These metrics focus on the input stream entered by the user independent of the time for transcription. Participant 6 had particularly wide confidence intervals for these metrics when data for the letters only typing condition was examined; data for the word prediction enhanced typing condition more closely tracked that of the other participants.

Participant 6 had difficulty targeting the keys on the on-screen keyboard and relied on word prediction extensively when it was available. She used word prediction to reduce both the number of keystrokes required and errors. This participant had the highest corrected error rate and the highest average wasted bandwidth with a large confidence interval.

Utilized bandwidth or useful information transfer was on par between the able-bodied group and the participants with disabilities. Differences in list search times and the number of fixations on various locations were unremarkable.

While differences in the mean values depended on the performance measures being examined, the confidence intervals for the able-bodied group tended to be smaller than the corresponding intervals for the individual participants with disabilities. The larger variation in performance may complicate the development of models to describe performance by these participants.

8.4 RESEARCH QUESTION 4: FEASIBILITY OF MODELING

Modeling becomes feasible when users adopt consistent strategies or patterns of behavior to perform tasks. Strategies are comprised of primitive operations whose execution times must also be consistent. When multiple strategies emerge as being appropriate for completion of a particular task, guidelines are required for strategy selection.

8.4.1 Sequences of Actions

Consistency across subjects in the sequences most commonly used supports the creation of models which are applicable across user populations. The data showed preferences for sequences involving fixations on the keyboard but the probabilities for the sequences varied both across subjects and across keystroke event types. For letter keystroke events, the difference between the probabilities of the first and second most common sequences was pronounced, thereby showing a strong preference for a particular pattern which is highly conducive to modeling. However, for other keystroke event types such as transitions, there were not such pronounced differences in the probabilities of the most common sequences indicating that participants had not adopted such clear patterns. It is possible that the limited number of trials did not give participants enough practice with less frequent keystroke event types and subsequently clear patterns did not have a chance to develop.

Consistency within subjects is also necessary for model development. Data showed some preferences for particular sequences but the magnitude of the probabilities varied throughout the test session. This variation did not appear to be a function of practice or learning as no trends were evident.

8.4.2 Consistent Time for Primitive Operations

In general, as shown in Figure 15, the participants had relatively tight confidence intervals for time between keystrokes with the average for the able-bodied group clearly below that of the participants with disabilities. Participant 3 showed a particularly large variation in time between keystrokes but the variation in list search time was relatively small. This participant had some difficulty using the trackball efficiently as he preferred to keep it on his lap instead of on the table surface.

Confidence intervals for list search time, as shown in Figure 29, indicated that Participant 4 had large variation most likely due to difficulties mentioned earlier related to eye tracking. There was no clear distinction between the able-bodied group and the participants with disabilities in regards to the average duration of a word prediction list search.

8.4.3 Uncertainty in a Proven Model

In this study word prediction list search time was taken directly from the eye tracking data whereas in the study performed by Koester and Levine (18), list search time was estimated by subtracting the time for a keystroke from the time for a list search and keystroke. Estimating list search time in this manner yields significantly different search times as it includes other activities such as fixations on the presented and transcribed text as part of the list search. Table 31 shows the actual and estimated list search times in seconds.

Table 31. Actual and estimated word prediction list search time in seconds

participant	actual search time	derived search time	% error
able-bodied	0.179	0.230	-28.489
participant 1	0.252	0.495	-96.422
participant 3	0.096	0.259	-169.759
participant 4	0.613	1.158	-88.878
participant 5	0.308	0.480	-55.698
participant 6	0.058	0.024	58.808

The calculated confidence intervals for the actual list search time and time between keystrokes were used in Koester and Levine's (18) KLM model of performance with word prediction. Koester and Levine modeled two strategies their participants were asked to follow. Participants following the first strategy were asked to search the word prediction list prior to typing a character. The corresponding KLM model for a word which appeared immediately in the list is $t_s + t_k$. Participants following the second strategy were asked to enter two characters prior to searching the word prediction list. The corresponding KLM model for a word which appeared immediately in the list is $t_s + 3t_k$. Koester and Levine developed equations for each word individually. The following calculations of uncertainty assume that the target word always appeared in the word prediction list. Clearly any delay in the appearance of the word in the list would magnify the uncertainty. Mean values for time between keystrokes and list search duration were assumed to be zero in order to simplify calculations and to clearly isolate the component of uncertainty. Table 32 shows the cumulative uncertainty for each strategy.

Table 32. Uncertainty for each strategy (sec)

	strategy 1	strategy 2
able-bodied	0.102	0.236
participant1	0.143	0.249
participant3	0.799	2.336
participant5	0.111	0.211
participant6	0.296	0.606

Uncertainty for model predictions varied among the able-bodied group and the individual participants with disabilities. Participants 1 and 5 most closely tracked performance variation showed by the able-bodied group. Participant 3 showed the greatest variation with uncertainty using strategy 2 being a factor of 10 greater than that of the able-bodied group. This is a function of the time between keystrokes confidence interval discussed above.

8.4.4 Summary

While the first research question determined that users do adopt strategies used to interact with the system, identification of those strategies and the conditions guiding their selection for completion of a particular task are unclear. Execution times for primitive operations were reasonably consistent for list search time but varied between the able-bodied group and participants with disabilities for time between keystrokes.

Parameters for primitive operations affected by physical limitations should be different for able-bodied individuals and individuals with disabilities. If models are to be created a priori, execution times for primitive operations such as keystroke time, mouse movement, etc. must be gathered from individuals with disabilities and made available to model developers in a similar manner to the parameters currently available that apply to able-bodied individuals. Differences in other types of primitive operations would require further research into modifications necessary to calibrate existing modeling techniques to make them applicable for different user groups.

The third research question showed that confidence intervals were often wider for participants with disabilities. The calculations of uncertainty in a proven model illustrate the effect of those wider intervals by comparing uncertainty of model predictions for able-bodied participants and participants with disabilities. In order to accurately predict performance of individuals with disabilities, a modeling technique must be able to accommodate wider confidence intervals in some manner.

9.0 CONCLUSIONS

In order to successfully model the collected data, a modeling technique must be capable of selecting from among multiple sequences of behavior used to perform a particular type of action. While by definition GOMS models can accommodate multiple methods capable of performing a particular task, the collected data shows that selection rules may be difficult to develop. The technique must also accommodate variation in the execution time for primitive operations which could potentially become excessive depending on the ability of the user. Actions should be defined at a finer level of granularity than that provided by the KLM to support visibility into fixations on areas outside the word prediction list. These fixations are important as they could indicate an increase in mental workload experienced by the user. The use of GOMS variants is precluded as errors must be handled gracefully instead of assumed nonexistent.

While this research did not conclusively answer the defined research questions, contributions were made in terms of knowledge gained relative to the design of the test bench and experimental protocol.

10.0 FUTURE WORK

An overriding conclusion based on the data analysis is the need to better define what constitutes a fixation in terms of both duration and deviation. In addition to the size of the word prediction list, the visual angle should be considered to determine how much of the list the participant is able to view without eye movement. Resolution of this matter will require research on visual search and consultation with the engineers from ISCAN. Limitations of the current equipment may prohibit the ideal settings but a clear understanding of the issues involved should be attained prior to further data collection with the test bench.

The test bench should be modified to capture time stamped mouse movement in addition to keystroke and eye tracking information. This will provide information concerning parallel activities such as fixating on the word prediction list while moving the mouse to the on-screen keyboard. Parallel activity is an important part of human information processing and could also provide insight into the learning process if the study is modified to collect data in multiple sessions.

In order to better address the research questions, the experimental protocol should be modified to support multiple test sessions and possibly use of a word prediction application at home. This would allow participants to practice and gain experience using the system. Performance should be tracked at intervals to determine if patterns or sequences of behavior are developing and if quantitative measures of performance show improvement.

Physical ability of the participants should be assessed in a quantitative manner allowing data for participants to be grouped for the purpose of performing comparisons. In this manner the able-bodied group would not necessarily be defined as able-bodied but would be defined according to ability and could possibly include participants with disabilities that do not affect computer use. Perhaps Compass could be used to perform this assessment. More participants with disabilities should be recruited. Confidence intervals could be computed for each group and then compared to examine the effect of ability as opposed to the comparisons performed in this study which examined each participant with a disability individually.

In the event that comparisons are desired between actions used to perform different types of keystroke events, the test bench software must be modified to induce a greater number of events such as fix and transition keystrokes. Additionally, consideration should be given to the distribution of typing condition relative to the number of trials completed by each participant.

The test bench could also be modified to present individual words for transcription instead of sentences. This would support the computation of text entry rate on a per word basis and allow more detailed comparisons between typing conditions. With the proposed modification, the use of word prediction would be determined on a per word basis depending on detection of a fixation on the word prediction list. In the test bench setup used for this study, data was partitioned based on word prediction being enabled, not on whether it was used. Text entry rate could only be calculated on a per sentence basis due to the appearance of the sentence in its entirety and the desire to include time for cognition in the text entry rate, i.e. the participant could have read three words then transcribed each from memory. The cognitive time related to reading and transcribing a single word could not be isolated.

APPENDIX A: TEXT ENTRY INTERFACE OUTPUT

```
Subject Name = example data

Sentence Group:
Start Sentence = 1
End Sentence = 5

Configuration:
Show Word Prediction List when 0 letter(s) is/are typed
Hide Word Prediction List when 20 letter(s) is/are typed after the list is
displayed
Max List size = 5
Min Word Size = 1

Target Sentences are :
Sentence number 1 is -> i agree with you the music is better than it sounds
Sentence number 2 is -> fish are jumping neither a borrower nor a lender be
Sentence number 3 is -> play it again sam please provide your date of birth
Sentence number 4 is -> the cotton is high my favorite subject is psychology
Sentence number 5 is -> the living is easy never too rich and never too thin

Simulation parameters are :

Initial Time = 1166110519044  -> this is the time in milliseconds since the
start of the Unix epoch (January 1, 1970, 00:00:00 GMT)
Type: (from eventRecord)
      INCORRECTFIXED = 0;
      INCORRECTNOTFIXED = 1;
      FIX = 2;
      WPSELECTION = 3;
      LETTER = 4;
      SPACE = 5;
      TRANSITION = 6;
      PAUSE_START = 7;
      PAUSE_END = 8;
      KEY_UP = 9;
      IGNORED = 10;

Text: input text from this event

WPL Len: number of entries in the wp list

WPL Disp: wp list displayed? t/f

Total Time: time since start of trial
```

WPL Contents: entries in wp list

```
Type  Text  WPL Len     WPL Disp    Total Time  WPL Contents
7           0     false 11203
8           0     false 16266
4     i     8     true  17500 the that you they this take time think
9           0     false 17579
9           0     false 17610
5     _     0     true  19219
9           0     false 19329
4     a     8     true  20954 the that you they this take time think
9           0     false 21157
4     g     2     true  21844 and are
9           0     false 21954
4     r     2     true  22016 again ago
9           0     false 22141
3     ee    2     true  23329 agree agreed
9           0     false 23422
      .
      .
```

Total Searches: 32 -> **number of times the word prediction list appeared**
The following keystroke measures are defined in Soukoreff and MacKenzie (2004).
Total Keystrokes: 32 -> **total number of keystrokes entered**
Correct: 51.0 -> **alphanumeric keystrokes that are not errors**
Incorrect Not Fixed: 0.0 -> **errors that appear in the transcribed text**
Incorrect Fixed: 0 -> **errors in the input stream that are corrected in the transcribed text**
Fixes: 0 -> **keystrokes that perform corrections (backspace)**
The following metrics are defined in Soukoreff and MacKenzie (2003).
MSD Error Rate = 0.0 -> **minimum string distance – minimum number of primitives required to transform the transcribed string into the presented string**
KSPC = 0.6274509803921569 -> **keystrokes per character – length of the input stream / length of the transcribed text**

TER = 1.4440433212996389 –> **text entry rate in characters per second**

The same data appears for each of the five sentences.

APPENDIX B: MORAE CONFIGURATION

Each recording file contains data for either a single block of five sentences or two blocks depending on how fast the sessions were being completed. The decision to partition the data into multiple files was made based on convenience, not limitations in the recording length. As mentioned in a previous section, the recommended screen resolution for use with the recorder is 1024x768. Figure 51 and Figure 52 are screen shots of the Morae Recorder; the configuration used for all of the participants is shown. Settings appear in the main window while a preview of the webcam is shown in the pane to the right. The configuration includes specification of filename, folder, capture options, and recording initiation and termination.

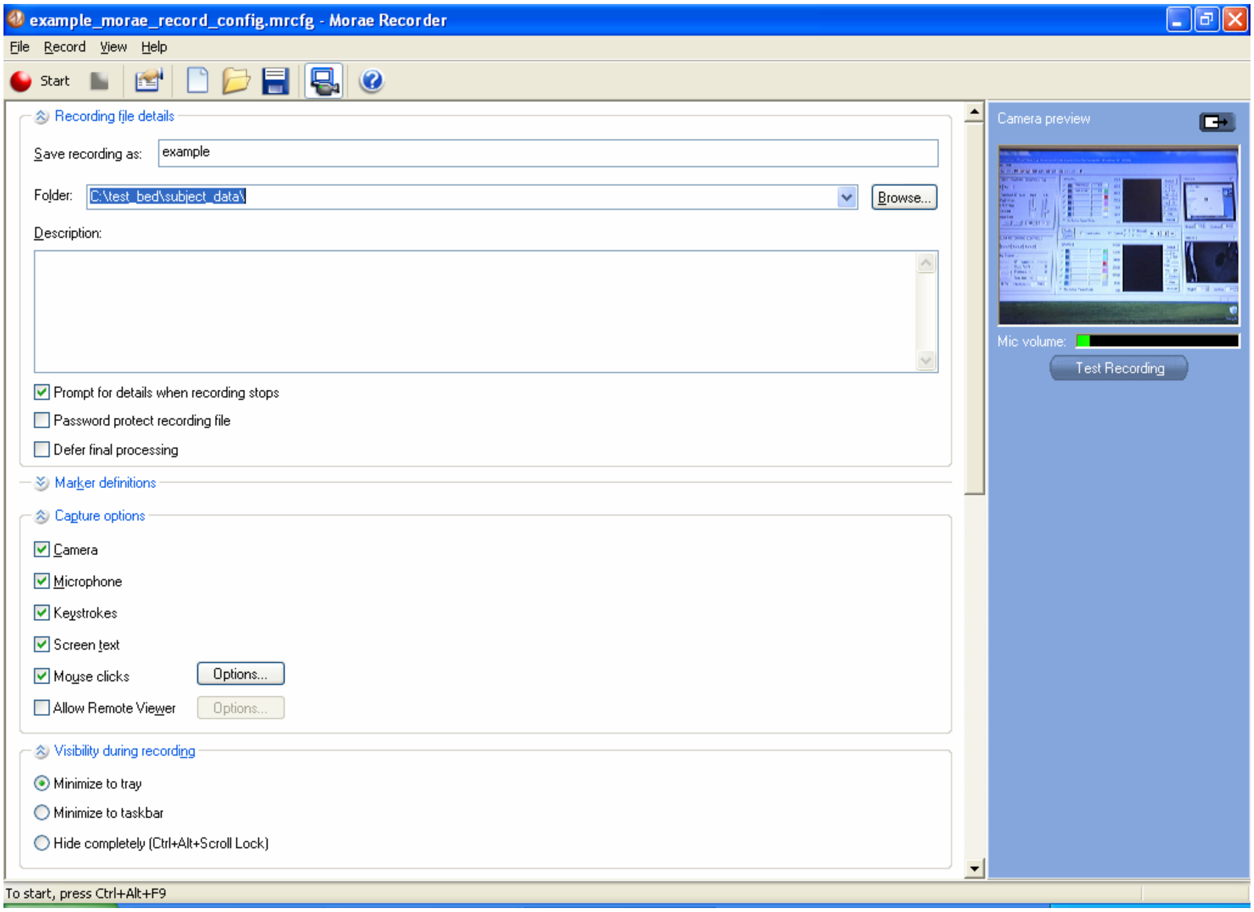


Figure 51. Screen shot of first half of Morae recorder configuration

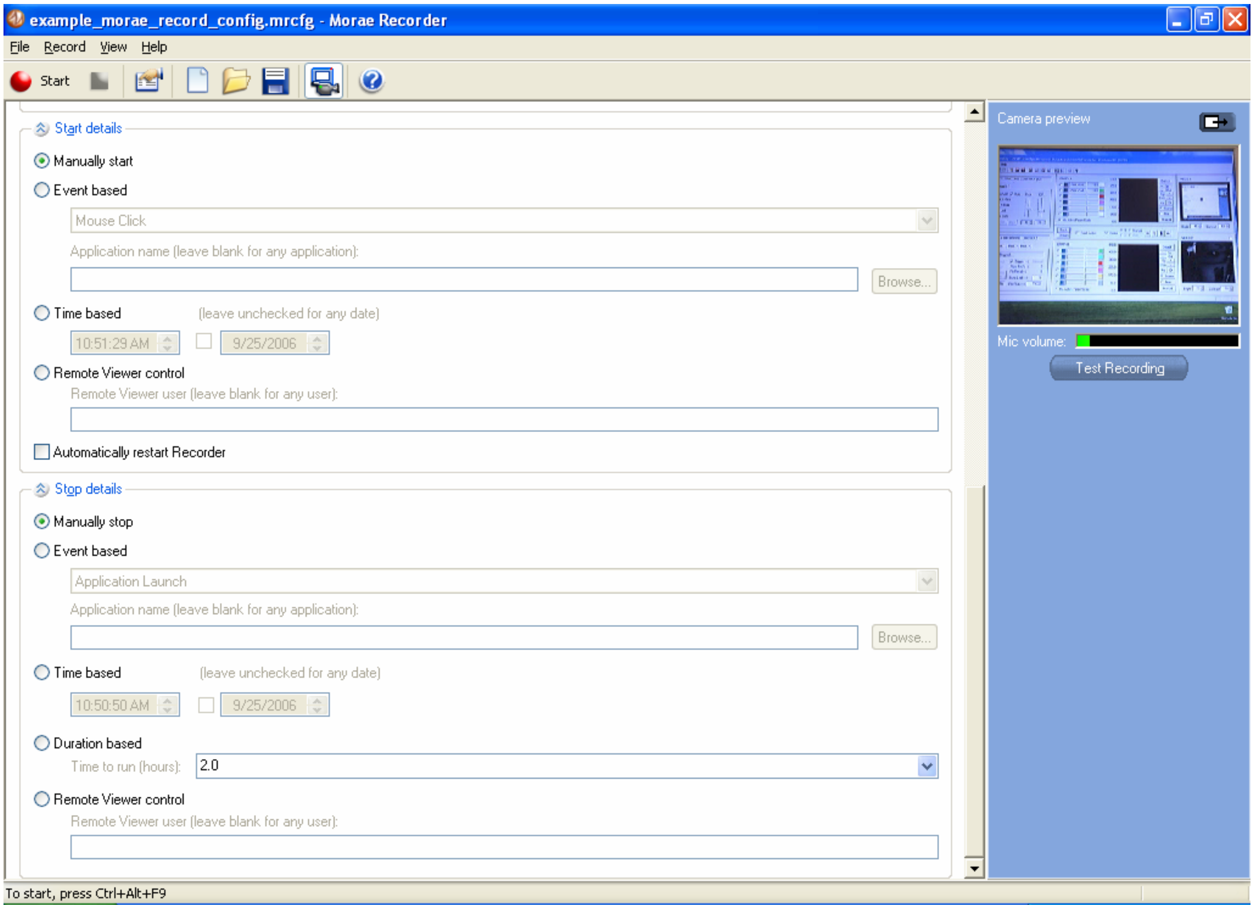


Figure 52. Screen shot of second half of Morae recorder configuration

APPENDIX C: DQW OUTPUT FILES

Point of regard and fixation data were stored for each group of five sentences. The following is an example of the point of regard data output with comments in bold.

```
ISCAN Tab-Delimited ASCII Data File
Version 4.00

ISCAN Data Recording

Runs Recorded:    1
Samps Recorded:   13401

RUN INFORMATION TABLE
Run # Date        Start Time  Samples     Samps/Sec   Run Secs    Image File
      Description
   1  2006/12/14   14:22:54     13401          60       223.35
full_screen_ab.igr -> this is the name of an image registration file

DATA SUMMARY TABLE
POR H1AB -> point of regard horizontal (x coordinate on screen) considering
gaze of both eyes
POR V1AB -> point of regard vertical (y coordinate on screen) considering
gaze of both eyes
                  Raw         Raw
Run # Param       Mean        StdDev
   1
      POR H1AB      126.13       47.7277
      POR V1AB      365.29       75.4069

DATA INFO
                  x           y     coordinates
Run   1:    POR H1AB    POR V1AB
Sample #    (Raw)       (Raw)
       0       74.50      247.00
       1       74.50      246.00
       2       75.00      246.50
       3       75.50      248.00
       4       75.50      250.50
       5       76.00      253.00
```

Fixation data was generated based on the point of regard data and a fixation time setting of 40 milliseconds. The following is an example of the fixation data output with comments in bold.

ISCAN P.O.R. Fixation Data File, Version 2.1
calibration -> **job name/ # (from run event sequence file)**
test -> **job type (from run event sequence file)**
0
0
Pitt -> **test location (from run event sequence file)**
1 30 2006 -> **date**
200 2600 222
60
442 0 3 3
512 512 -> **overall resolution (from image registration file)**
130 390 -> **registration point coordinates x y (upper left)**
366 263 -> **registration point coordinates x y (upper right)**
192 329 -> **registration point coordinates x y (lower left)**
359 316 -> **registration point coordinates x y (lower right)**
full_screen_ab.igr -> **image registration file identified in the run event sequence file**
1 0 13401 -> **file shown 1 time, captured starting at sample 0, captured 13401 samples**
fixation data -> start sample #, end sample #, x coordinate, y coordinate
233 234 416 289 -> **start sample = 233, end sample = 234, x = 416, y = 289**
235 237 404 294
277 278 18 289

APPENDIX D: PRZ – DETAILS OF USE

The application is run both before and after the actual collection of data. Prior to data collection with DQW, PRZ is used to create image registration and run event sequence files. Image registration files identify bitmap images and specific coordinates on them that serve as registration points. These registration points, when combined with the registration points in the DQW application, provide the information necessary to create scale factors used to map the collected data onto the image for viewing purposes. The image registration files are used by the PRZ program for the display of collected data. The following is an example image registration file with comments in bold.

```
ISCAN Image Registration File, Version 1.0

C:\subject_data\wpgui_std\full_screen_ab.bmp -> absolute path to the bitmap
512 392 -> size of display
126 67 386 67 127 323 386 323 -> coordinates of the registration points
```

The run event sequence files are used to provide configuration information needed by the DQW program in order to generate fixation data. The following is an example run event sequence file with comments in bold.

```
ISCAN Image Sequence Data File, Version 2.0
Initials -> job name/ #
data collection -> job type
0
0
Pitt -> test location
```

```
1 120 -> respondent id # range - minimum and maximum
0
1 -> number of images in the sequence = runs limit in dqw
full_screen_ab.igr -> list of registered images included in the run event
sequence
```

Following data collection with DQW, fixation data can be analyzed and viewed with PRZ. Figure 53 is a screen shot of the defined elements of interest on the registered image.

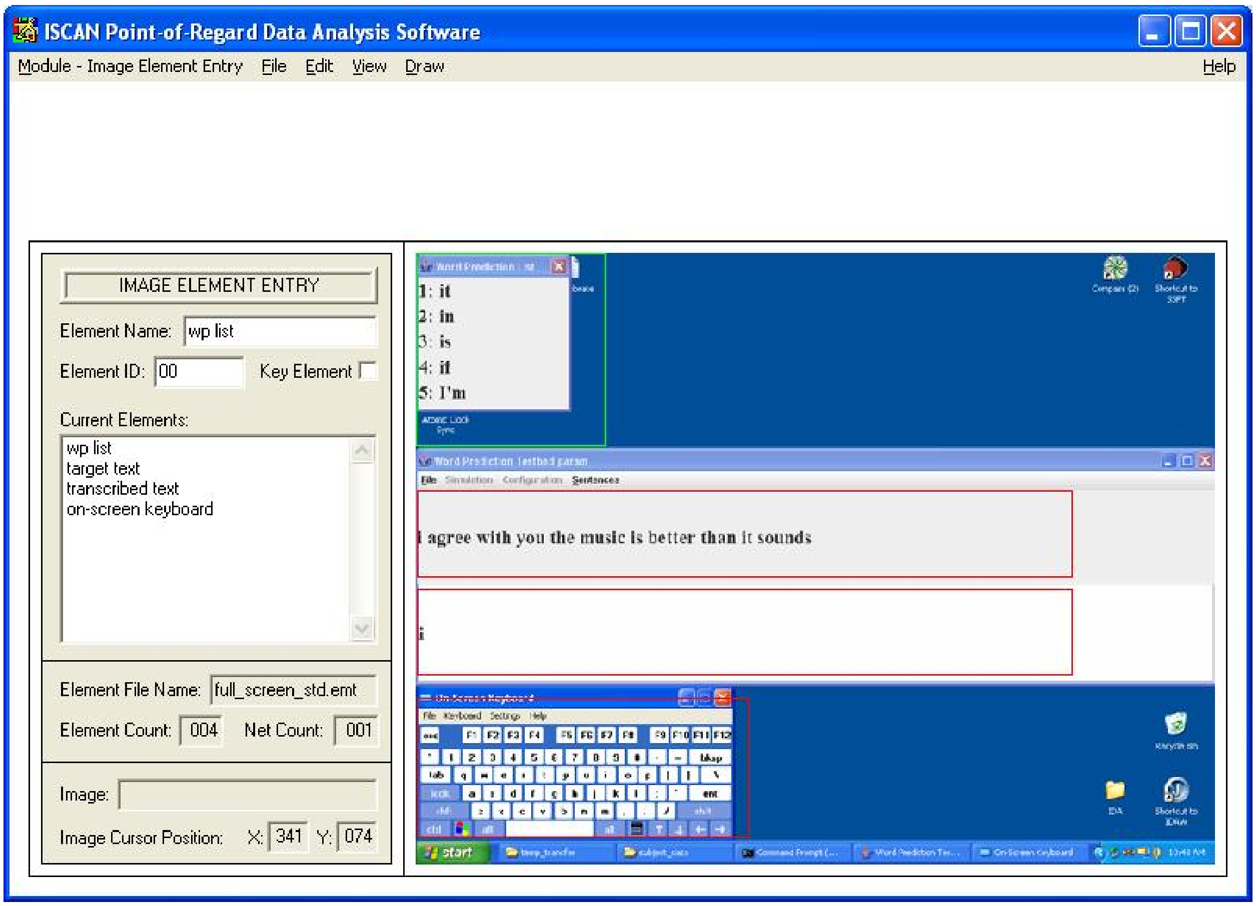


Figure 53. Screen shot of PRZ showing defined areas of interest

Areas of interest are defined as being slightly larger than the actual windows to accommodate poor calibration and drift as the ISCAN machine heats up. Figure 11 shows a screen shot of the PRZ display showing fixations identified from collected data overlaying the registered bitmap. Figure 54 shows the same output without the saccades.

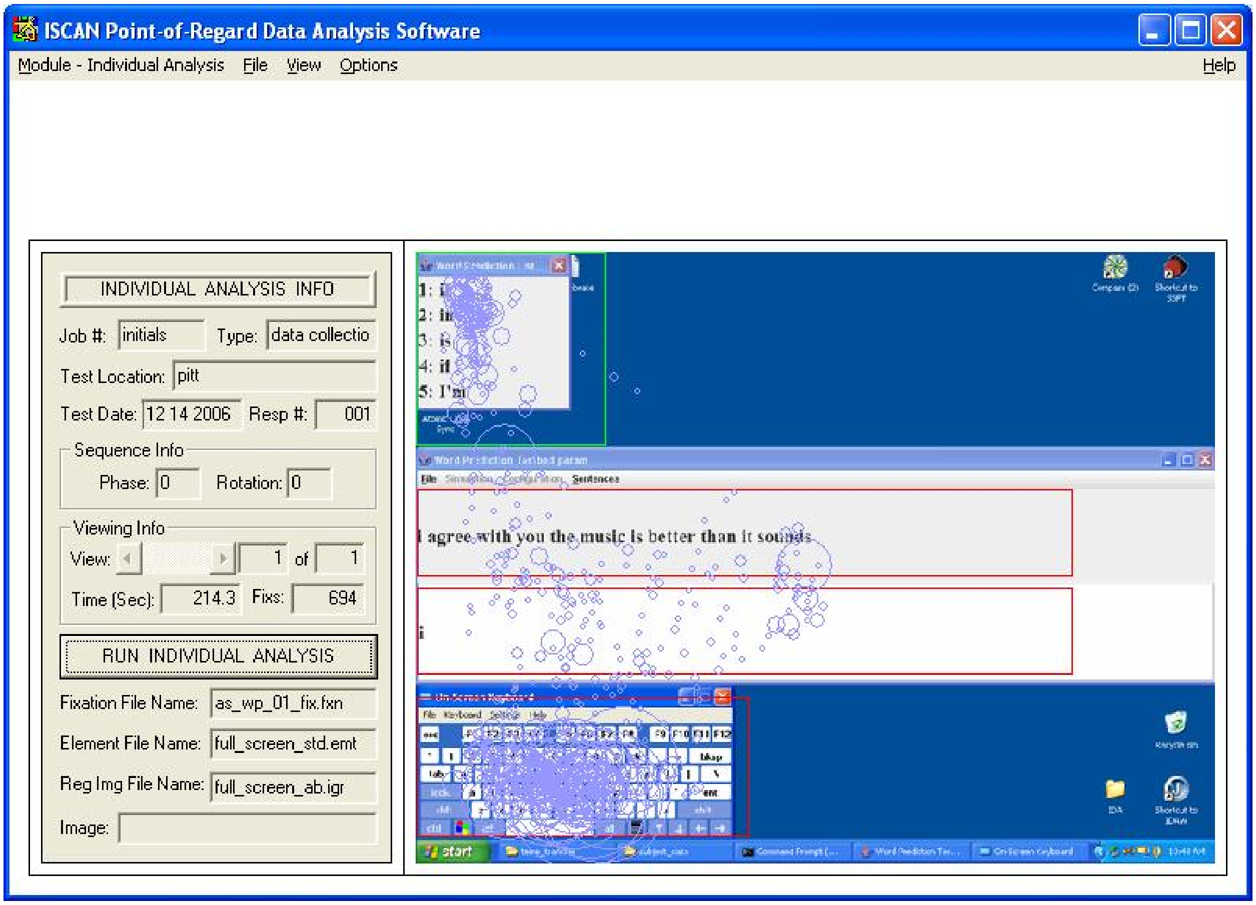


Figure 54. PRZ fixation viewing screen shot without saccades

The following is an example fixation list created from collected data.

```
INDIVIDUAL ANALYSIS - LIST OF ELEMENT FIXATIONS TABLE

Job Name/#:  initials
Project Type:  data collection
Image Name:
Element File:  full_screen_std.emt
Fixation File: as_wp_01_fix.fxn
Respondent ID: 1
View #:  1 of 1

                  Individual Element Fixations in Order

                                                  Start    Fixation
Fixation    Element         X         Y          Time     Duration
 Number      Name        Position  Position     (Sec)      (Sec)
```

0	on-screen keybo	141	345	0.00	0.13
1	on-screen keybo	128	348	0.15	0.02
2	on-screen keybo	81	344	0.18	0.38
3	on-screen keybo	61	338	0.58	0.03
4	on-screen keybo	70	336	0.63	0.03
5	on-screen keybo	79	337	0.68	0.02
6	on-screen keybo	90	337	0.72	0.03
7	on-screen keybo	122	341	0.77	0.53
8	transcribed tex	65	257	1.57	0.13
9	on-screen keybo	49	341	1.95	0.32
10	on-screen keybo	124	348	2.30	1.68
11	on-screen keybo	58	360	4.00	0.38
12	on-screen keybo	93	348	4.40	0.28
13	transcribed tex	118	238	4.75	0.02
14	transcribed tex	119	240	4.78	0.02
15	transcribed tex	101	226	4.88	0.02
16	No Element	78	211	4.97	0.03
17	target text	71	205	5.02	0.02
18	target text	55	194	5.10	0.03
19	on-screen keybo	86	343	5.55	1.82
20	target text	41	183	7.80	0.02
21	target text	37	185	7.83	0.02
22	on-screen keybo	70	337	8.27	0.40
23	wp list	34	23	8.75	0.02
24	wp list	33	30	8.78	0.68
25	on-screen keybo	41	308	9.88	0.08

APPENDIX E: DATA COLLECTION SETUP

<u>Subject's PC</u>

- Remove old wp log files
  - C:\test_bed\WPJava
  - del *.wp
- Copy entire c:\test_bed\ subject_data\initials folder
  - rename based on subject's initials
  - delete folders that will not be used based on tests listed in subject_summary.xls (latin square)
- Start the Morae Recorder
  - File->Open Configuration
    - C:\test_bed\subject_data*initials*\morae_record_config.mrcfg
    - Save recording as:
      - *Initials* (will append configuration_sentences to each)
    - Folder:
      - C:\test_bed\subject_data*initials*\
  - File->Save Configuration As
    - *initials*_morae_record_config.mrcfg
- Start the HDD USB Monitor
  - Open c:\test_bed\subject_data\mouse_usb_monitor or trackball_usb_monitor
  - Initiate capture [F9]
  - Move the mouse or trackball to confirm operational
  - Stop capture [F12]
  - Export [ctrl + e] c:\ test_bed\subject_data*initials*\test.html
  - (this will set up directory for saving, can discard test file later)
  - Clear the view [Delete]
  - Resize the window so that it fits behind the wpgui window
- Open a DOS window to c:\test_bed\WPJava\
  - Run the word prediction test bed
    - java –classpath "." wpgui
- Start the on screen keyboard
  - Note: keyboard selection will actually be based on a cutoff text entry rate during the practice trials. If a subject types at less than 0.65 char/sec (8 words/min) with the standard on-screen keyboard then WiViK will be used.
  - If for some reason the desktop shortcut is gone:

        - Start->All Programs->Accessories->Accessibility->On-Screen Keyboard
    - Select Keyboard->Standard Layout
    - Unselect Settings->Always on Top
    - Align the keyboard along the lower left corner of the screen above start
      OR

    - Start WiViK
        - Keyboard – USENGLSH_SIMPLE.KBP
- After positioning the on-screen keyboard against the task bar, auto hide the task bar to prevent the subject from accidentally opening another window.
- Start Atomic Clock Sync [ctrl + alt + a]
    - Ping Now
        - This will synchronize the clock setting
    - Close Atomic Clock Sync
- Open calibrate.ppt and show slide show (F5)

<u>ISCAN PC</u>

- Copy entire c:\test_bed\ subject_data\initials folder
    - rename based on subject's initials
    - delete folders that will not be used based on tests listed in subject_summary.xls (latin square)
- Start Atomic Clock Sync
    - Ping Now
        - This will synchronize the clock setting
    - Close Atomic Clock Sync
- Start DQW1_11A
    - File->Open ISCAN Run Event Seq File->
        - c:\subject_data\wpgui_std\wpgui.seq OR
        - c:\subject_data\wpgui_wivik\wpgui.seq
    - Maximize VIDEO 1 by checking the box at the upper right
    - Select Options [button is near the bottom of the screen, in the middle]
        - Keep hitting button until POR CALIBRATION CONTROLS appears to the left
    - Select the POR 1 tab
        - Click the POR Calibrate radio button
            - Place each of the calibration markers over the corresponding marker on calibrate.ppt shown in the video 1 expanded view
                - Use the Select Point button to move from one marker to the next
        - Click the Image Reg radio button
            - Place each of the registration markers over the corresponding marker on calibrate.ppt shown in the video 1 expanded view [there is no center registration marker]

        - Use the Select Point button to move from one marker to the next
    - Click on the Reset radio button
- Select the Options button (bottom of the screen) until DATA RECORDING CONTROLS appears to the left
    - Select the Bank 1 tab
    - Confirm the following:
        - 01 -> .POR.H1AB (point of regard for both eyes, horizontal)
        - 02 -> .POR.V1AB (point of regard for both eyes, vertical)
    - Select the Record tab
        - Confirm the following:
            - Trigger check box is checked -> Internal
            - Runs Rec'd -> 0 (if not Delete Last)
            - Runs Limit -> 1
            - 60 Hz All Pts

<u>Subject's PC</u>

- Close calibrate.ppt
- Open the Morae Recorder and check the camera preview to be sure the web cam is positioned properly
- Open seq_calibrate.ppt [ctl + alt + c]
    - Start the slide show (F5)

APPENDIX F: CONSENT FORM

Department of Rehabilitation Science and Technology
School of Health and Rehabilitation Sciences • University of Pittsburgh

Forbes Tower, Suite 5044
Pittsburgh, PA 15260
412.383.6596
Fax 412.383.6597
TDD: 412.383.6598
www.shrs.pitt.edu/rst

Approval Date: May 27, 2005
Renewal Date: May 26, 2006
University of Pittsburgh
Institutional Review Board
IRB #0303139

CONSENT TO ACT AS A SUBJECT IN A RESEARCH STUDY

TITLE: Developing a user model for a word prediction interface

PRINCIPAL INVESTIGATOR: Richard Simpson, Ph.D.
Assistant Professor
Department of Rehabilitation Science and Technology
University of Pittsburgh
Suite 5044, Forbes Tower
Telephone: 412-383-6593
ris20@pitt.edu

SOURCE OF SUPPORT: National Science Foundation

Why is this research being done?

You are being asked to participate in a research study to develop models of how people interact with alternative computer access technology. In this research study, we will record your actions (keystrokes and eye movements) while you use alternative computer access technology to enter some text. We will use this information to evaluate how well different models match the results we observe.

Who is being asked to take part in this research study?

You are being invited to take part in this research study because you are between 21 to 65 years of age. People invited into this study can be male or female, and may or may not have a physical, perceptual or cognitive impairment that interferes with their ability to access a computer. The study is being performed on a total of 20 individuals here at the University of Pittsburgh.

What procedures will be performed for research purposes?

If you decide to take part in this research study, you will undergo the following procedures that are not part of your standard medical care:

Screening Procedures:

Procedures to determine if you are eligible to take part in a research study are called "screening procedures". For this research study, the screening procedures include:

1. Talking to you about your current computing habits. We will be particularly interested in how often you use the computer and whether you can access a computer without assistance.

Training Procedures:

If you qualify to take part in this research study, you will undergo the following training procedures:

1.	A training session to familiarize you with the alternative computer access technology and text-entry interface that will be used with this study. At the end of the training session, you will be asked to use the alternative computer access technology to enter text.

Experimental Procedures:

If you qualify to take part in this research study, you will undergo the following experimental procedure:

1.	You will be given a sequence of sentences to enter, one at a time, using alternative computer access technology. While you perform the tasks, we will record keystrokes and mouse movements and use an eye tracking system to monitor your visual attention. We will also record data about your hand and finger movements and the electrical activity in your brain. This will require you to wear an accelerometer on your wrist, three electrodes on your index finger, and a "swim cap" with many electrodes embedded in it.

Monitoring/Follow-up Procedures:

Procedures performed to evaluate the safety and effectiveness of the experimental procedures are called "monitoring" or "follow-up" procedures. For this research study, the monitoring/follow-up procedures include:

1. Between trials, you will be asked if you are experiencing any fatigue or discomfort.

You are free to go home after the trials are completed.

The entire session is expected to last no longer than two hours:

- Screening Procedures: 15 minutes

- Training Procedures: 30 minutes
- Experimental Procedures: 1 hour and 15 minutes

What are the possible risks, side effects, and discomforts of this research study?

The possible risks of this research study are the same associated with normal computer use. These include the possibility that you might become fatigued or uncomfortable from sitting down in front of the computer and typing for too long.

What are possible benefits from taking part in this study?

You will likely receive no direct benefit from taking part in this research study.

If I agree to take part in this research study, will I be told of any new risks that may be found during the course of the study?

You will be promptly notified if any new information develops during the conduct of this research study that may cause you to change your mind about continuing to participate.

Will my insurance provider or I be charged for the costs of any procedures performed as part of this research study?

Neither you, nor your insurance provider, will be charged for the costs of any of the procedures performed for the purpose of this research study (i.e., the Screening Procedures, Training Procedures, Experimental Procedures, or Monitoring/Follow-up Procedures described above).

Will I be paid if I take part in this research study?

You will not be paid for taking part in this study.

Who will know about my participation in this research study?

All records related to your involvement in this research study will be stored in a locked file cabinet. Your identity on these records will be indicated by a case number rather than by your name, and the information linking these case numbers with your identity will be kept separate from the research records. Only the researchers listed on the first page of this form and their staff will have access to your research records. Your research records will be destroyed when such is approved by the sponsor of this study or, as per University policy, at 5 years following study completion, whichever should occur last.

Any information about you obtained from this research will be kept as confidential (private) as possible. You will not be identified by name in any publication of research results unless you sign a separate form giving your permission (release). In unusual cases, your research records may be released in response to an order from a court of law. It is also possible that authorized representatives of the Food and Drug Administration, the study sponsor (National Science Foundation), and/or the University Research Conduct and Compliance Office may inspect your research records.

The fact that you are participating in a research study and that you are undergoing certain research procedures (but not the results of the procedures) may also be made known to individuals involved in insurance billing and/or other administrative activities associated with the conduct of the study.

Is my participation in this research study voluntary?

Your participation in this research study is completely voluntary. You do not have to take part in this research study and, should you change your mind, you can withdraw from the study at any time. Your current and future care at a UPMC facility and any other benefits for which you qualify will be the same whether you participate in this study or not.

If I agree to take part in this research study, can I be removed from the study without my consent

It is possible that you may be removed from the research study by the researchers. Subjects will be removed from this study if they have not completed the session within two and one-half hours or if they appear to be experiencing excessive fatigue or discomfort.

Approval Date:
Renewal Date:
University of Pittsburgh Institutional Review Board
IRB #

****

VOLUNTARY CONSENT

All of the above has been explained to me and all of my current questions have been answered. I understand that I am encouraged to ask questions about any aspect of this research study during the course of this study, and that such future questions will be answered by the researchers listed on the first page of this form.

Any questions I have about my rights as a research participant will be answered by the Human Subject Protection Advocate of the IRB Office, University of Pittsburgh (1-866-212-2668).

By signing this form, I agree to participate in this research study. A copy of this consent form will be given to me.

_______________________________ _______________
Participant's Signature Date

_______________________________ _______________
Witness Signature Date

INVESTIGATOR'S CERTIFICATION

I certify that the nature and purpose, the potential benefits and possible risks associated with participation in this research study have been explained to the above individual and that any questions about this information have been answered.

_______________________________ _______________
Investigator's Signature Date

APPENDIX G : PRELIMINARY QUESTIONNAIRE – TRANSCRIPTION STUDY

Preliminary Questionnaire – Transcription Study

Participant Code: ________
Interviewer: ____________
Date: __________________

I. Participant Information

This first section asks for some basic information about you.

1. Sex: M F 2. Age: ______ 3. Dominant hand: L R
4. Disability (what, when): ____

____

5. Education: ____
6. Any difficulties with reading or writing? N Y (specify) ________________
7. Employed currently? N Y (specify job, weekly hours): ________________

____

8. Attending school currently? N Y (specify school, course load): ______________

____

II. Pattern of Computer Usage

This section asks about your general pattern of computer usage and the types of tasks you do with your computer.

9. On average, how many hours per week do you use your computer? (If you have trouble thinking of an average, think back over the last two weeks.)
   - [] less than 2 hours
   - [] 2 to 5 hours per week
   - [] 6 to 10 hours per week
   - [] 11 to 20 hours per week
   - [] 21 or more hours per week

10. When you use the computer, what sorts of things do you do? Check all that apply.
    - [] browse the web
    - [] email
    - [] word processing
    - [] finance
    - [] games
    - [] other: ______________________

APPENDIX H: CONSUMER SURVEY

Consumer Survey

Name ____
First MI Last

Address 1 ____

Address 2 ____

City ____________________ State ________ Zip ____

Phone Home ____________________ ☐ Preferred

Work ____________________ ☐ Preferred

Cell ____________________ ☐ Preferred

E-Mail Home ____________________ ☐ Preferred

Work ____________________ ☐ Preferred

I prefer to be contacted by

☐ No Preference ☐ Phone ☐ Mail ☐ E-Mail

Date of Birth ____ / ____ / ____ Gender ☐ Male ☐ Female

Ethnicity

☐ African American/Black ☐ Caucasian/White

☐ Asian American ☐ Hispanic

☐ Other ____________________

Education (check all that were completed)

☐ Did not graduate high school

☐ High School

☐ Associates Degree Field of Study ________

☐ Bachelor's Degree Field of Study ________

☐ Master's Degree Field of Study ________

☐ Doctoral Degree Field of Study ________

☐ Currently in school Field of Study ________

Diagnosis

☐ SCI Years Post-Injury ________

Level ________

☐ TBI Years Post-Injury ________

☐ ALS Years Post-Diagnosis ________

☐ MS Years Post-Diagnosis ________

☐ MD Years Post-Diagnosis ________

☐ CP

☐ Post-Polio Syndrome Years Post-Diagnosis ________

☐ Stroke Years Post-Diagnosis ________

☐ Other ____________________

Mobility Aids

☐ Cane ☐ Scooter

☐ Walker/Rollator ☐ Manual Wheelchair

☐ Crutches ☐ Power Wheelchair

Visual Acuity	☐	Do not need eyewear	☐	Contact Lenses
	☐	Wear Glasses	☐	Legally Blind
Computer Literacy	☐	Novice/Never use	☐	Beginner/Limited experience
	☐	Intermediate	☐	Expert/Extensive experience

APPENDIX I : CALIBRATION PROCEDURE

<u>ISCAN PC</u>

- Position the subject's eyes in the VIDEO 2 display
  - Can manually adjust camera position / height and use P/T Control (pan/tilt)
  - Center the subject's eyes in the display
  - Allow space for slight horizontal head movement
- Check the Track Active check box (bottom near the middle of the window)
- Click on the Tracks button until EYE TRACKING CONTROL (1,2) appears in the upper left
- Select the Eye 1 Tab
  - Check the following check boxes:
    - Threshold
    - Pupil X-Hairs
    - C.R. X-Hairs
    - C.R. Limit
  - The subject's pupils should appear white with black crosshairs; the corneal reflections should appear as black dots with white crosshairs.
    - If the crosshairs are not visible for both eyes:
      - Uncheck the Auto check box
      - Manually adjust the Pupil and C.R. sliders to set the boundaries of the pupils and the corneal reflections.
- Select the POR Calibrate radio button in the POR CALIBRATION CONTROLS POR 1 tab
  - Ask the subject to focus on the marker on the first slide
  - Confirm that the crosshairs appear over BOTH eyes
  - Enter Calib Pt
  - The marker should automatically move to the next calibration point

<u>Subject's PC</u>

- Advance to the next slide in the slide show (can left click the mouse or enter)

<u>ISCAN PC</u>

    - Ask the subject to focus on the marker on the slide
    - Confirm that the crosshairs appear over BOTH eyes
    - Enter Calib Pt
    - The marker should automatically move to the next calibration point
    - Continue the process for the remaining three calibration points
- Select the Reset radio button
    - The POR Output radio button should become active
        - If the POR Output radio button does not become active:
            - Repeat the calibration procedure, making absolutely certain that BOTH sets of crosshairs appear over BOTH eyes!
- Select the POR Output radio button
- Ask the subject to look up, down, left and right, confirming that the marker on the VIDEO 1 EXPANDED VIEW follows the direction of their gaze
    - If the marker does not follow the direction of their gaze:
        - Repeat the calibration procedure, making absolutely certain that BOTH sets of crosshairs appear over BOTH eyes!
- At this point the marker on the VIDEO 1 EXPANDED VIEW should be tracking the subject's gaze
    - If it is not:
        - Consider adjusting the angle of the camera relative to their eyes
        - Note that if the subject is wearing glasses:
            - The glare will be worst when the lenses are perpendicular to the plane of the camera, try to adjust the angle of the lenses!
            - Ask the subject to put their chin down
            - Move the glasses slightly up or down the nose
        - Repeat the calibration procedure using dark_calibrate.ppt, making absolutely certain that BOTH sets of crosshairs appear over BOTH eyes!
- File->Save ISCAN POR Calib File As->
    - c:\subject_data*subject_name**initials*_por_calib.pcl

APPENDIX J: PRACTICE PROCEDURE

<u>Subject's PC</u>

- Close seq_calibrate.ppt [alt + space, c]
- Allow the subject to do a practice session consisting of the last sentence group in their sequence with word prediction enabled. The subject may transcribe as many of the sentences in the group as they wish to support acclimation to the test environment.
  - File->Parameters->Word Prediction tab
    - Word Prediction Active: *true*
  - select the desired Sentence Group via the menu
  - Instruct the subject to enter the target sentence via the on-screen keyboard and not to position the mouse in the transcribed text field.
  - Instruct the subject not to lift the mouse for repositioning.
  - Instruct subject to only use the white keys on the keyboard, no arrows for positioning within the text field.
  - Inform the subject that it is his or her choice as to whether to correct errors or not.
  - Instruct the subject to hit the on-screen keyboard enter key when a sentence is complete.
  - Explain how to select items from the word prediction list and specifically mention that a selected item includes the space following the word.
  - Mention that during the data collection some sentence groups will be entered via letters only typing and others will be entered with word prediction enabled.
  - Ask the subject to hold his or her head still while transcribing the text. Explain that there is room for very slight head movement.
  - Explain the pause and 3 beeps between sentences.
  - Reiterate that the subject may do as many sentences as they wish to become acclimated to the test environment, stress that we would like at least 2 complete sentences to use for a TER check
  - File->Start Trial

<u>ISCAN PC</u>

- Monitor the VIDEO 2 display to be sure that the subject's eyes remain in view and the crosshairs remain over both eyes until the subject finishes practicing
  - Click the P/T Control Auto radio button to allow the software to perform the adjustments

- NOTE – do <u>not</u> record data for this practice trial, give the subject feedback on head positioning and movement
- When the subject has completed the practice trials unclick the track active check box
- Select the Options button (bottom of the screen) until DATA RECORDING CONTROLS appears to the left
    - Delete Last to remove old data
    - Confirm Runs Rec'd -> 0

<u>Subject's PC</u>

- Note: check the text entry rate (TER) for the practice sentences. If TER < 0.65 char/sec (8 words/min) then switch to the WiViK on-screen keyboard and do another practice trial. **If the keyboard is switched then we MUST load the other sequence file in the ISCAN DQW application!!!!!!!!**
- Insert the subject's name in the parameters dialog
    - File->Parameters->Trial tab
        - Subject Name: *subject_name*

APPENDIX K: DATA COLLECTION PROCEDURE

- Start the Morae Recorder
  - Start data collection [ctrl + alt + f9]
- Word Prediction Testbed
    - File->Parameters->Word Prediction tab [alt + f, p]
      - Word Prediction Active: *true* or *false*
    - select the desired Sentence Group [alt + s, down arrow]
- Start USB sniffer
  - [alt + tab] make window active
  - [F9] start capture
  - Move <u>subject's</u> mouse to upper left of screen (0,0) and <u>right</u> click 5 times
  - Move <u>subject's</u> mouse back down to the wpgui and left click to make it the active window (and hide the usb sniffer)

<u>ISCAN PC</u>

- Check the Track Active check box (bottom near the middle of the window)
- Click the P/T Control Auto radio button to allow the software to perform adjustments that will accommodate slight head movement.

<u>Subject's PC</u>

- Word Prediction Testbed
  - Start the trial [alt + f, s]

<u>ISCAN PC</u>

- DATA RECORDING CONTROLS Record Tab
  - **<u>Click on the Start Record radio button</u>**
- Monitor the VIDEO 2 display to be sure that the subject's eyes remain in view and the crosshairs remain over both eyes until the subject completes the trial
- WHEN THE SUBJECT HAS COMPLETED THE SENTENCE GROUP…
- DATA RECORDING CONTROLS Record Tab

    - Click on the Quit Record radio button
- Uncheck the Track Active check box (bottom near the middle of the window)
- IF CONTINUING IMMEDIATELY TO THE NEXT SENTENCE GROUP:
- File->Save ISCAN Raw Data File As-> [alt + f, a]
    - c:\subject_data*subject_name*\ *initials_configuration_sentences*_raw
- File->Save ISCAN POR Fixation File As->
    - Choose Fixation Parameters
        - #1 – POR Calib
        - Source AB
        - Continue >>
    - Enter Respondent ID Info
        - New ID#
            - *xy*
        - Enter Track ID (n, a->f)
            - n
        - Finish
    - Save in:
        - c:\subject_data*subject_name*
    - File name:
    - *initials_configuration_sentences*_fix
    - Save as type:
        - ISCAN POR Fixation Files (*.fxn)
- Open folder c:\subject_data*subject_name*
    - Confirm the following are present:
        - *initials_configuration_sentences*_raw.dqw
        - *initials_configuration_sentences*_fix.fxn
- Select the Options button (bottom of the screen) until DATA RECORDING CONTROLS appears to the left
    - Delete Last to remove old data
    - Confirm Runs Rec'd -> 0
- Check the Track Active check box (bottom near the middle of the window)
- ELSE:
- Subject can relax and move out of view of the camera

<u>Subject's PC</u>

- IF CONTINUING IMMEDIATELY TO THE NEXT SENTENCE GROUP:
- Word Prediction Testbed
    - Select the next sentence group for the subject [alt + s, down arrow]
    - Start the trial [alt + f, s]
- ELSE:
- Stop USB sniffer
    - [alt + tab] make window active
    - [F12] stop capture
    - [ctrl + e] Export to file *subject_name_configuration_sentences*_usb.html

  - Confirm the data file was written
  - Clear the view [Delete]
- Morae Recorder
  - Stop recording [ctrl + alt + f9]
  - Recording File Details
    - Save recording as:
      - *subject_name_configuration_sentences*
    - Folder:
      - c:\test_bed\subject_data\ *subject_name*\
    - Add any relevant notes in the description
    - OK
    - File->Exit
- Atomic Clock Sync
  - Ping Now
    - This will synchronize the clock setting

<u>ISCAN PC</u>

- File->Save ISCAN Raw Data File As-> [alt + f, a]
  - c:\subject_data*subject_name*\ *initials_configuration_sentences*_raw
- File->Save ISCAN POR Fixation File As->
  - Choose Fixation Parameters
    - #1 – POR Calib
    - Source AB
    - Continue >>
  - Enter Respondent ID Info
    - New ID#
      - *xy*
    - Enter Track ID (n, a->f)
      - n
    - Finish
  - Save in:
    - c:\subject_data*subject_name*
  - File name:
  - *initials_configuration_sentences*_fix
  - Save as type:
    - ISCAN POR Fixation Files (*.fxn)
- Open folder c:\subject_data*subject_name*
  - Confirm the following are present:
    - *initials_configuration_sentences*_raw.dqw
    - *initials_configuration_sentences*_fix.fxn
- Select the Options button (bottom of the screen) until DATA RECORDING CONTROLS appears to the left
  - Delete Last to remove old data
  - Confirm Runs Rec'd -> 0

- Atomic Clock Sync
    - Ping Now
        - This will synchronize the clock setting

APPENDIX L: DATA STORAGE PROCEDURE

Network Drive

- Copy L:\Simpson Lab\Jen\subject_data\subject_name
  - Rename with subject's initials
  - L:\Simpson Lab\Jen\subject_data*initials*
- Should have 2 sub-folders
  - L:\Simpson Lab\Jen\subject_data*initials*\subject_pc
  - L:\Simpson Lab\Jen\subject_data*initials*\iscan_pc

Subject's PC

- Copy c:\test_bed\WPJava*.wp c:\ test_bed\subject_data\ *subject_name*\wpgui_out
- Copy c:\test_bed\WPJava\ *inititals*x.wp to c:\ test_bed\subject_data\ *subject_name**initials_ configuration_sentences*.wp
- Word Prediction Data
  - Open c:\test_bed\subject_data\ *subject_name**initials_ configuration_sentences*.wp with Wordpad and confirm there is data.
- HHD USB Monitor data
  - Open c:\test_bed\subject_data\ *subject_name*\ *initials_configuration_sentences*_usb.html (can save as a text file) and confirm there is data (timestamp and many mouse movement events).
- Recording Data
  - Start Morae Manager
    - Create a new project
    - Project name:
      - morae_project_*initials_configuration_sentences*
    - Project folder:
      - c:\test_bed\subject_data*subject_name*\
    - Next
    - Add
      - c:\test_bed\subject_data*subject_name*\ *subject_name_configuration_sentences* .rdg
      - Open
    - Finish

        - Should see recording
        - File->Exit
- Copy c:\test_bed\subject_data*subject_name**   L:\Simpson Lab\Jen\subject_data*initials*\subject_pc\

<u>ISCAN PC</u>

- Start PRZ1_02E
    - Module – Image Element Entry->Individual Analysis
    - File->Open->
        - Look in:
            - c:\subject_data\wpgui_std\ or c:\subject_data\wpgui_wivik
        - File name:
            - full_screen_std or full_screen_wivik
        - Files of type:
            - Image Element Files (*.EMT)
        - Open
    - A bitmap with the word prediction application main window, word prediction list dialog and the onscreen keyboard should appear. Rectangles outline areas of fixation interest.
    - In the INDIVIDUAL ANALYSIS INFO pane to the left:
        - Element File Name: full_screen_std.emt
        - Reg Image File Name: wpgui_kb_std.igr OR wpgui_kb_wivik.igr
        - Image: wpgui with keyboard
    - File->Open->
        - Look in:
            - c:\subject_data\ *subject_name*\
        - File name:
            - *initials_configuration_sentences*_fix
        - Files of type:
            - POR Fixation Data Files (*.FXN)
        - Open
    - Fixations should appear superimposed on the bitmap.
    - In the INDIVIDUAL ANALYSIS INFO pane to the left:
        - Fixation File Name: *initials_configuration_sentences*_fix.fxn
        - The RUN INDIVIDUAL ANALYSIS button should be active
    - Click on the RUN INDIVIDUAL ANALYSIS button
    - View->List of Element Fixations
    - The display should show a list of individual element fixations in order.
    - File->Saved Table Style->Formatted ASCII
    - File->Save Displayed Table As->
        - c:\ subject_data\ *subject_name*\
        - *initials_configuration_sentences*_fix_list.txt

    - File->Exit Program
- Copy all fixation files to c:\ subject_data\ *subject_name*\fixation_out\
- Copy c:\test_bed\subject_data*subject_name**   L:\Simpson Lab\Jen\subject_data*initials*\iscan_pc\

Network Drive

- Contents:
    - L:\Simpson Lab\Jen\subject_data*initials*\subject_pc
        - \wpgui_out\ [all wpgui output files]
        - *initials*_morae_record_config.mrcfg [morae recorder config]
        - For each configuration + sentence combination
            - *initials_configuration_sentences*.wp
            - *initials_configuration_sentences*_usb.html
            - *initials_configuration_sentences*.rdg
            - \ morae_project_*initials_configuration_sentences*\ [entire folder]
    - L:\Simpson Lab\Jen\subject_data*initials*\iscan_pc
        - For each configuration + sentence combination
            - *initials_configuration_sentences*_fix_list.txt
            - *initials_configuration_sentences*_fix.fxn
            - *initials_configuration_sentences*_raw.dqw
        - *initials*_por_calib.pcl [will only appear when calibration was done, not for every sentence group]

APPENDIX M: POST PROCESSING PERL SCRIPTS

M.1 PARSE_WORD_DATA_FILES.PL

This script is run by the following command line:

perl parse_word_data_files.pl *absolute_path_to_directory_containing_files*

Files in the specified directory should include any number of the following:

configuration_sentencegroup.wp

*configuration_sentencegroup*_raw.tda

*configuration_sentencegroup*_fix_list.txt

The script runs the following command line for each .wp file in the specified directory:

perl parse_word_data.pl *configuration_sentencegroup*.wp

This script synchronizes the data from the *configuration_sentencegroup*.wp and *configuration_sentencegroup*_fix_list.txt. Note that *configuration_sentencegroup*_raw.tda is only used to provide an initial timestamp for the ISCAN data. Only data for words entered free of errors is included in the output file due to the complexity of maintaining an awareness of what the subject believes the target word is. When something unexpected occurs in the input stream it is difficult to identify the subject's intent. The following shows the format of the output file, word_data.xls followed by an example.

```
# column A - target sentence #
# column B - target word
# column C - target word length
# column D - target char
# column E - target char position in word
# column F - is target word in word prediction list?  [remember this is the
list prior to the current char entry!]
# column G - duration of word prediction list fixations during the time
interval associated with entry of this char
# column H - was word prediction used?
# column I - duration of target text fixations during the time interval
associated with entry of this char
# column J - duration of transcribed text fixations during the time interval
associated with entry of this char
# column K - duration of on-screen keyboard fixations during the time
interval associated with entry of this char
# column L - string of codes indicating the sequence of events which occurred
during entry of the character
      #
      # character event codes:
      # 0 - reserved - no event
      # 1 - target text fixation
      # 2 - transcribed text fixation
      # 3 - word prediction list fixation
      # 4 - on-screen keyboard fixation
      # 5 - character entered
      # 6 - number entered for word prediction selection
      #
# column M - the time from PAUSE_END(8) or KEY_UP(9) to WPSELECTION(3) or
LETTER(4) = time between keystrokes (seconds)
# column N - number of word prediction list fixations during the time
interval associated with entry of this char
# column O - number of presented (target) text fixations during the time
interval associated with entry of this char
# column P - number of transcribed text fixations during the time interval
associated with entry of this char
# column Q - number of on-screen keyboard fixations during the time interval
associated with entry of this char
# column R - positive search -> list search when word was in the list
# column S - false positive search -> list search when word was not in the
list
# column T - negative search -> no list search when word was not in the list
# column U - false negative search -> no list search when word was in the
list
# column V - successful search -> target word selected during search when
target word was in the list
# column W - unsuccessful search -> target word not selected during search
when target word was in the list
# column X - number of words in wp list
#
```

A	56	56	56	56	56	56	56	56	56	56
B	see	see	see	you	you	you	later	later	later	later

C	3	3	3	3	3	3	5	5	5	5
D	s	e	e	y	o	u	l	a	t	e
E	1	2	3	1	2	3	1	2	3	4
F	0	1	1	0	1	1	0	0	1	1
G	0	0	0	0	0	0	0.03	0	0	0.33
H	0	0	1	0	0	1	0	0	0	1
I	0	0	0	0.07	0	0	0	0	0	0
J	0	0	0	0	0	0	0.02	0	0	0
K	1.22	0	0.15	2.17	0	0	0.02	0	1.13	0
L	545	55	546	145	5	6	32455	55	45	536
M	1.454	0.484	0.859	1	0.687	1.204	1.156	0.656	0.906	1.25
N	0	0	0	0	0	0	1	0	0	3
O	0	0	0	1	0	0	0	0	0	0
P	0	0	0	0	0	0	1	0	0	0
Q	1	0	1	2	0	0	1	0	1	0
R	0	0	1	0	0	1	0	0	0	1
S	0	0	0	0	0	0	1	0	0	0
T	1	0	0	1	0	0	0	1	0	0
U	0	1	0	0	1	0	0	0	1	0
V	0	0	1	0	0	1	0	0	0	1
W	0	0	0	0	0	0	0	0	0	0
X	5	5	5	5	5	5	5	5	5	5

M.2 CREATE_LIST_SEARCH_SUMMARY.PL

This script is run by the following command line:

perl create_list_search_summary.pl word_data.xls

This script summarizes information concerning list searches on a per sentence basis. The following shows the format of the output file, search summary.xls followed by an example.

```
#
# column A - sentence #
# column B - # positive list searches - User searched list when word was in
list
# column C - duration of positive list searches
# column D - positive list search time (column C / column B) --- time for a
single positive list search
# column E - # false positive list searches - User searched list when word
was not in list
# column F - duration of false positive list searches
# column G - false positive list search time (column F / column E) --- time
for a single false positive list search
# column H - # negative list searches - User did not search list when word
was not in list
# column I - duration of negative list searches
# column J - negative list search time (column I / column H) --- time for a
single negative list search
# column K - # false negative list searches - User did not search list when
word was in list
# column L - duration of false negative list searches
# column M - false negative list search time (column L / column K) --- time
for a single false negative list search
# column N - successful anticipation - (Positive searches + Negative
searches)/(total searches)
# column O - # successful searches - User selected the target word during a
search in which the target word was displayed in list
# column P - duration of successful searches
# column Q - successful list search time (column P / column O) --- time for a
single successful list search
# column R - # unsuccessful searches - User did not select the target word
during a search in which the target word was displayed in list
# column S - duration of unsuccessful searches
# column T - unsuccessful list search time (column S / column R) --- time for
a single unsuccessful list search
# column U - # presented text fixations
# column V - duration of presented text fixations
# column W - # transcribed text fixations
# column X - duration of transcribed text fixations
# column Y - # on-screen keyboard fixations
# column Z - duration of on-screen keyboard fixations
#
```

A	56	57	58	59	60

B	6	7	5	1	0
C	1	0.45	0.6	0.52	0
D	0	0.064	0.12	0.52	0
E	5	4	6	1	1
F	1	1.28	1.79	0.25	0.05
G	0	0.32	0.298	0.25	0.05
H	14	15	7	2	0
I	0	0	0	0	0
J	0	0	0	0	0
K	3	7	4	1	0
L	0	0	0	0	0
M	0	0	0	0	0
N	1	0.667	0.545	0.6	0
O	6	4	2	1	0
P	1	0.12	0.02	0.52	0
Q	0	0.03	0.01	0.52	0
R	0	3	3	0	0
S	0	0.33	0.58	0	0
T	0	0.11	0.193	0	0
U	4	9	6	2	0
V	0	0.37	0.82	0.05	0
W	6	13	10	0	0
X	0	0.81	0.32	0	0
Y	23	39	26	2	3
Z	11	10.43	6.1	1.05	0.3

M.3 PARSE_ALL_SENTENCE_SUMMARY_DATA_FILES.PL

This script is run by the following command line:

perl parse_all_sentence_summary_data_files.pl *absolute_path_to_directory_containing_files*

The script runs the following command line for each .wp file in the specified directory:

perl parse_sentence_summary_data.pl *configuration_sentencegroup*.wp

This script gathers keystroke summary information which includes all keystroke events and creates five output files. The format and an example of the data in each file are shown below.

```
# file: name_keystrokes.xls
# column A - sentence number
# column B - wp active?
# column C - number of correct keystrokes
# column D - number of incorrect not fixed keystrokes
# column E - number of incorrect fixed keystrokes
# column F - number of fix keystrokes
# column G - % correct keystrokes = C/(C+INF+IF+F)
# column H - correct keystrokes to total text-producing keystrokes =
C/(C+INF+F)
# column I - % errors = (INF+IF)/(C+INF+IF+F)
# column J - errors to total text-producing keystrokes = (INF+IF)/(C+INF+F)
# column K - participant conscientiousness = IF/(IF+INF)
# column L - utilised bandwidth = C/(C+INF+IF+F)
# column M - wasted bandwidth = (INF+IF+F)/(C+INF+IF+F)
# column N - total error rate = (INF+IF)/(C+INF+IF) x 100
# column O - not corrected error rate = INF/(C+INF+IF) x 100
# column P - corrected error rate = IF/(C+INF+IF) x 100
#
```

A	56	57	58	59	60
B	TRUE	TRUE	TRUE	TRUE	TRUE
C	53	51	54	51	52
D	0	0	0	0	0
E	1	1	5	5	0
F	1	1	5	5	0
G	0.963636	0.962264	0.84375	0.836066	1

H	0.981481	0.980769	0.915254	0.910714	1
I	0.018182	0.018868	0.078125	0.081967	0
J	0.018519	0.019231	0.084746	0.089286	0
K	1	1	1	1	
L	0.963636	0.962264	0.84375	0.836066	1
M	0.036364	0.037736	0.15625	0.163934	0
N	1.851852	1.923077	8.474576	8.928571	0
O	0	0	0	0	0
P	1.851852	1.923077	8.474576	8.928571	0

```
# file: name_keystroke_savings.xls
# column A - sentence number
# column B - wp active?
# column C - length of presented text
# column D - length of input stream
# column E - length of transcribed text
# column F - minimum keystrokes required (optimal wp use)
# column G - keystroke savings compared to letters only (length of
transcribed text)/(length of the input stream)
# column H - keystroke savings compared to optimal letters only (length of
presented text)/(length of the input stream)
# column I - keystroke savings compared to optimal wp (minimum keystrokes
required)/(length of the input stream)
#
```

A	56	57	58	59	60
B	TRUE	TRUE	TRUE	TRUE	TRUE
C	53	51	54	51	52
D	41	46	59	48	40
E	54	51	54	52	52
F	35	35	37	33	31
G	1.317073	1.108696	0.915254	1.083333	1.3
H	1.292683	1.108696	0.915254	1.0625	1.3

I	0.853659	0.76087	0.627119	0.6875	0.775

```
# file: name_text_entry_rate.xls
# column A - sentence number
# column B - wp active?
# column C - text entry rate in chars / sec
#
```

A	56	57	58	59	60
B	TRUE	TRUE	TRUE	TRUE	TRUE
C	1.457215	1.287065	1.132246	1.228182	1.706649

```
# file: name_keystroke_rate.xls
# column A - sentence number
# column B - wp active?
# column C - number of keystrokes (including enter)
# column D - time for trial in seconds (pause_end to enter)
# column E - keystroke rate in keystrokes / sec
#
```

A	56	57	58	59	60
B	TRUE	TRUE	TRUE	TRUE	TRUE
C	42	47	60	49	41
D	37.057	40.402	48.576	42.339	31.055
E	1.133389	1.163309	1.235178	1.157325	1.320238

```
# file: name_time_between_keystrokes.xls
# column A - sentence number
# column B - wp active?
# column C - average time between keystrokes [key up to key down] in seconds
#
```

A	56	57	58	59	60
B	TRUE	TRUE	TRUE	TRUE	TRUE

C	0.840098	0.825696	0.774034	0.842333	0.726775

M.4 PARSE_ALL_DATA_FILES.PL

This script is run by the following command line:

perl parse_all_data_files.pl *absolute_path_to_directory_containing_files*

The script runs the following command line for each .wp file in the specified directory:

perl parse_all_data.pl *configuration_sentencegroup*.wp

This script, which requires the same files as parse_word_data_files.pl, generates a file containing the event sequences that occur with each keystroke. All keystroke events are included in the output file all_data.xls. The following shows the format of all_data.xls followed by an example.

```
# column A - event type (field 0 from the wp file)
      # FIX = 2;  <Backspace>
      # WPSELECTION = 3;
      # LETTER = 4;
      # SPACE = 5;
      # TRANSITION = 6; <Enter>
# column B - text (field 1 from the wp file)
# column C - string of codes indicating the sequence of events which occurred
during this keystroke
      # 0 - no fixations found
      # 1 - target text fixation
      # 2 - transcribed text fixation
      # 3 - word prediction list fixation
      # 4 - on-screen keyboard fixation.
      # 5 - no element fixation (fixation outside the defined areas of
interest)
# column D - delta time - time for this keystroke event
```

A	4	3	4	4	3	4	4	3	4	4	4	4	3
B	d	o	n	o	t	s	a	y	a	n	y	t	hing
C	4	24153	3	2	4	0	0	3	41	4	3	3	41
D	1.282	1.000	0.704	0.609	0.688	0.766	0.187	0.985	0.719	0.672	0.578	0.500	0.812

M.5 PARSE_SEQUENCE_DATA.PL

This script is run by the following command line:

perl parse_sequence_data.pl all_data.xls

The script creates summary statistics for event sequences. The following shows the format of the output file, sequence_summary.xls followed by an example.

```
# column A - event type (field 0 from the wp file)
      # FIX = 2;  <Backspace>
      # WPSELECTION = 3;
      # LETTER = 4;
      # SPACE = 5;
      # TRANSITION = 6; <Enter>
# column B - string of codes indicating the sequence of fixations identified
      # 0 - no fixations found
      # 1 - target text fixation
      # 2 - transcribed text fixation
      # 3 - word prediction list fixation
      # 4 - on-screen keyboard fixation
      # 5 - no element fixation (fixation outside the defined areas of
interest)
# column C - number of times the string in column B occurred (throughout the
entire file)
# column D - probability of the string in column B occurring
note - this is per event type and sequence length,
ie. the number of times this particular x element sequence occurred / total
number of x element sequence occurrences for a given event type
```

A	LETTER	LETTER	LETTER	LETTER	LETTER	LETTER	LETTER	LETTER	LETTER	LETTER
B	2	4	5	1	3	25	42	54	52	45
C	462	1177	340	291	397	65	90	84	81	116
D	17.32283	44.13198	12.74841	10.91114	14.88564	6.238004	8.637236	8.06142	7.773512	11.13244

The script generates a second output file, sequence_analysis.xls which contains the transitional probability matrices for each event type. Examples are provided.

	target	transcribed	wp List	keyboard	outside	none	f(first)
target	0	4	8	21	6	18	57
transcribed	8	0	4	32	15	26	85
wp list	1	5	0	66	7	76	155
keyboard	16	29	38	0	22	160	265
outside	7	9	18	26	0	15	75
f(second)	32	47	68	145	50	295	637

	target	transcribed	wp list	keyboard	outside	none	f(first)
target	0	6	23	85	16	161	291
transcribed	48	0	9	116	65	224	462
wp list	6	27	0	80	9	275	397
keyboard	47	90	54	0	116	870	1177
outside	49	81	31	84	0	95	340
f(second)	150	204	117	365	206	1625	2667

APPENDIX N: Z-SCORE MATRICES

N.1.1 Participant a

	presented	transcribed	wp list	keyboard	outside	none
presented	0	**-3.872**	2.424	**7.632**	-0.925	-2.891
transcribed	**4.539**	0	**-3.865**	**6.882**	**5.574**	**-6.061**
wp list	**-4.718**	-2.014	0	**6.461**	**-4.791**	0.767
keyboard	**-3.871**	-1.563	-0.505	0	0.386	2.096
outside	**6.920**	**11.7135**	**4.993**	**4.635**	0	**-10.681**

N.1.2 Participant b

	presented	transcribed	wp list	keyboard	outside	none
presented	0	-1.180	-1.831	**11.715**	**5.172**	**-7.199**
transcribed	**5.713**	0	-1.688	**6.438**	2.595	**-5.658**
wp list	**-4.387**	**-4.645**	0	**7.749**	**4.231**	-2.957
keyboard	-3.317	0.860	-1.425	0	**-6.632**	**4.395**
outside	**7.803**	**4.432**	**12.508**	3.264	0	**-10.560**

N.1.3 Participant 1

	presented	transcribed	wp list	keyboard	outside	none
presented	0	2.313	**8.570**	0.269	0.446	**-4.726**
transcribed	0.694	0	-2.336	**11.757**	2.765	**-8.244**
wp list	2.039	**-4.064**	0	3.366	**-3.881**	1.520
keyboard	-3.034	**-4.360**	0.859	0	0.854	2.349
outside	-0.034	**11.192**	**-3.678**	**12.022**	0	**-11.818**

N.1.4 Participant 2

	presented	transcribed	wp list	keyboard	outside	none
presented	0	2.066	0.917	0.948	0.722	-3.029
transcribed	2.924	0	-0.942	-0.187	1.715	-2.708
wp list	0.830	-1.460	0	2.543	0.198	-1.908
keyboard	-2.866	-0.827	-2.280	0	0.982	2.392
outside	0.129	-0.500	1.228	**3.819**	0	-3.492

N.1.5 Participant c

	presented	transcribed	wp list	keyboard	outside	none
presented	0	**5.862**	**3.839**	-0.784	**5.155**	**-6.923**
transcribed	2.445	0	-0.621	-3.433	-0.957	2.179
wp list	-0.348	-0.847	0	0.499	1.367	-0.575
keyboard	**-6.073**	**5.175**	-1.074	0	**11.641**	**-9.786**
outside	-0.702	**6.828**	-0.485	**7.841**	0	**-9.334**

N.1.6 Participant 3

	presented	transcribed	wp list	keyboard	outside	none
presented	0	1.310	0.529	0.300	2.167	-2.954
transcribed	**6.316**	0	-1.649	-1.823	**4.880**	**-5.252**
wp list	-1.127	-0.056	0	-0.814	0.288	0.914
keyboard	**-6.144**	-3.400	-2.624	0	**9.862**	-3.286
outside	-1.076	-0.310	0.457	**10.042**	0	**-7.619**

N.1.7 Participant d

	presented	transcribed	wp list	keyboard	outside	none
presented	0	**5.152**	-0.095	-0.0313	3.558	**-4.234**
transcribed	**6.516**	0	-0.222	-0.223	**7.161**	**-5.892**
wp list	0.530	-1.167	0	2.263	0.073	-1.058
keyboard	**-5.188**	-2.720	-1.258	0	**11.233**	**-5.075**
outside	-1.135	-0.740	-0.626	**14.165**	0	**-8.642**

N.1.8 Participant 4

	presented	transcribed	wp list	keyboard	outside	none
presented	0	**4.600**	2.277	**4.554**	3.509	**-9.658**
transcribed	**4.617**	0	-3.024	**-4.144**	-3.242	1.774
wp list	**12.753**	**-5.950**	0	**-3.881**	**-5.754**	-0.839
keyboard	**-3.874**	**3.715**	-1.682	0	**7.543**	**-3.921**
outside	-2.257	3.366	-0.155	-1.562	0	0.038

N.1.9 Participant e

	presented	transcribed	wp list	keyboard	outside	none
presented	0	**6.220**	-0.789	-2.472	-2.018	-0.256
transcribed	**11.130**	0	**-9.350**	0.965	**11.593**	**-10.872**
wp list	**-6.009**	1.665	0	**-4.527**	0.730	**4.638**
keyboard	**-8.265**	**-8.780**	3.556	0	1.290	**7.205**
outside	1.846	**5.000**	**4.550**	**15.683**	0	**-18.924**

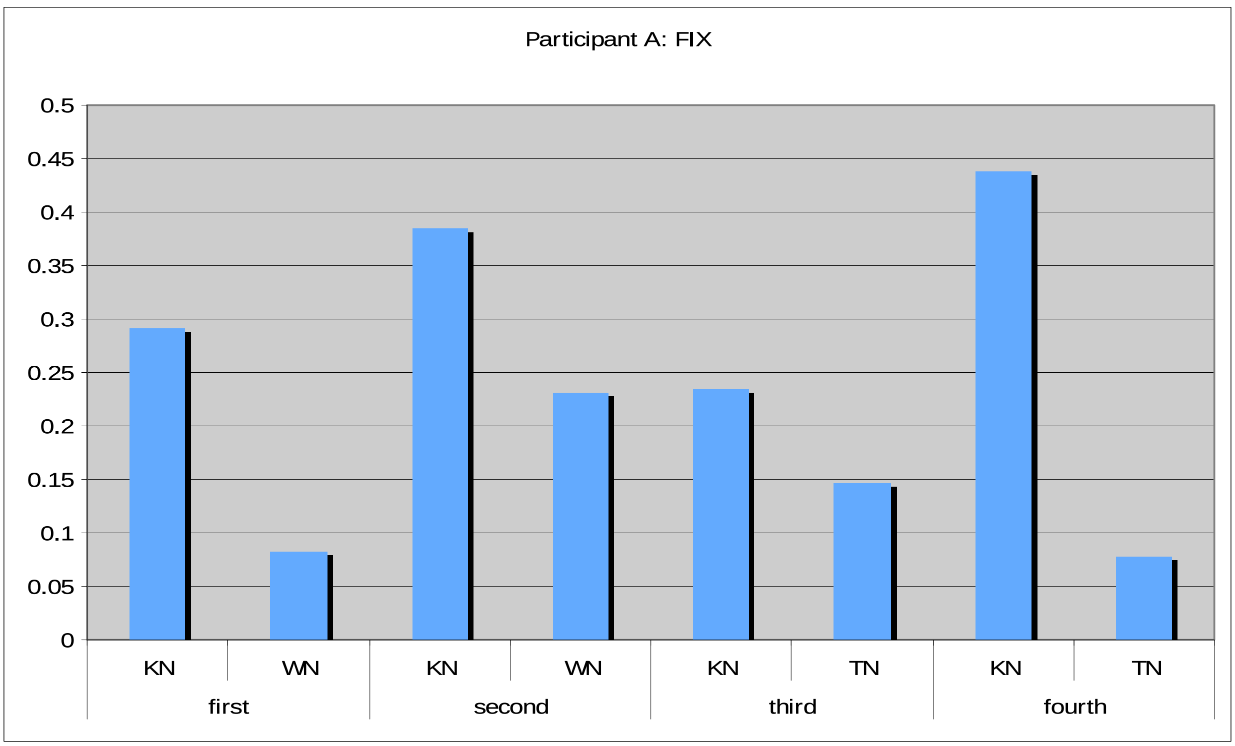
N.1.10 Participant 5

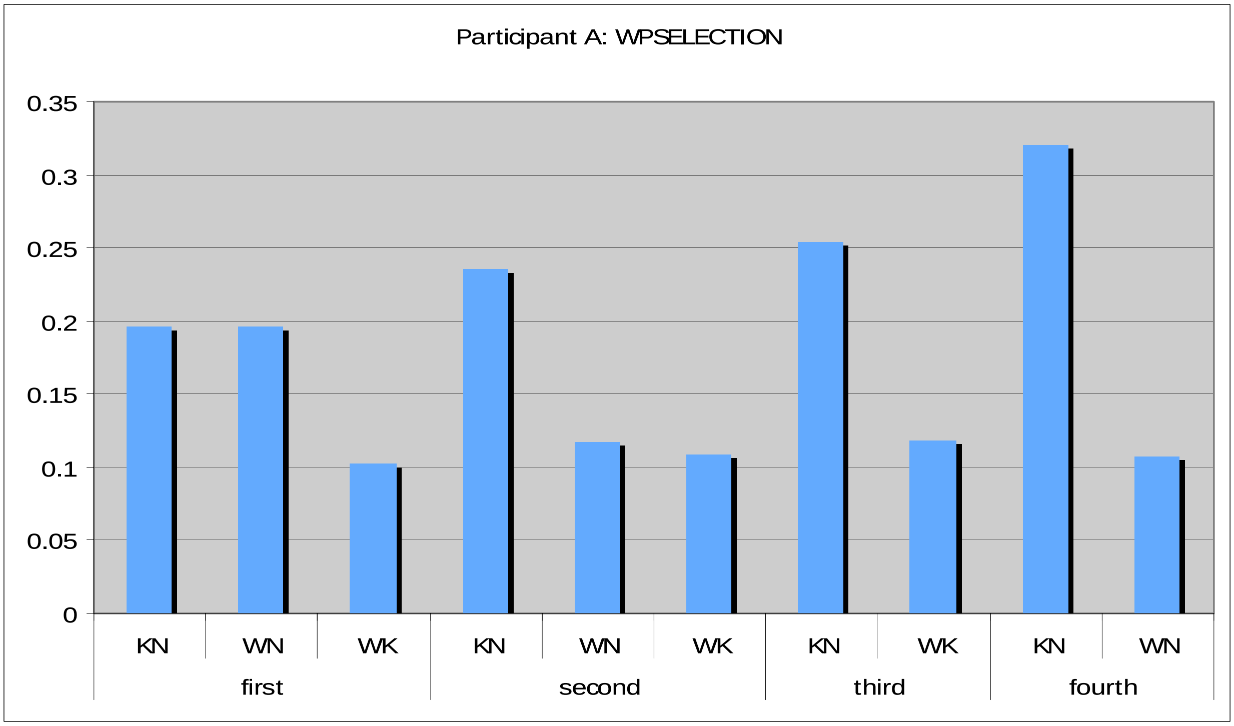
	presented	transcribed	wp list	keyboard	outside	none
presented	0	-1.712	-2.734	**11.047**	**10.143**	**-11.983**
transcribed	**8.176**	0	-2.561	**8.067**	**5.891**	**-12.182**
wp list	-3.093	-2.801	0	**12.211**	**5.212**	**-8.866**
keyboard	**-10.957**	0.312	-1.722	0	**-9.550**	**12.023**
outside	**11.063**	0.315	2.988	**16.423**	0	**-18.271**

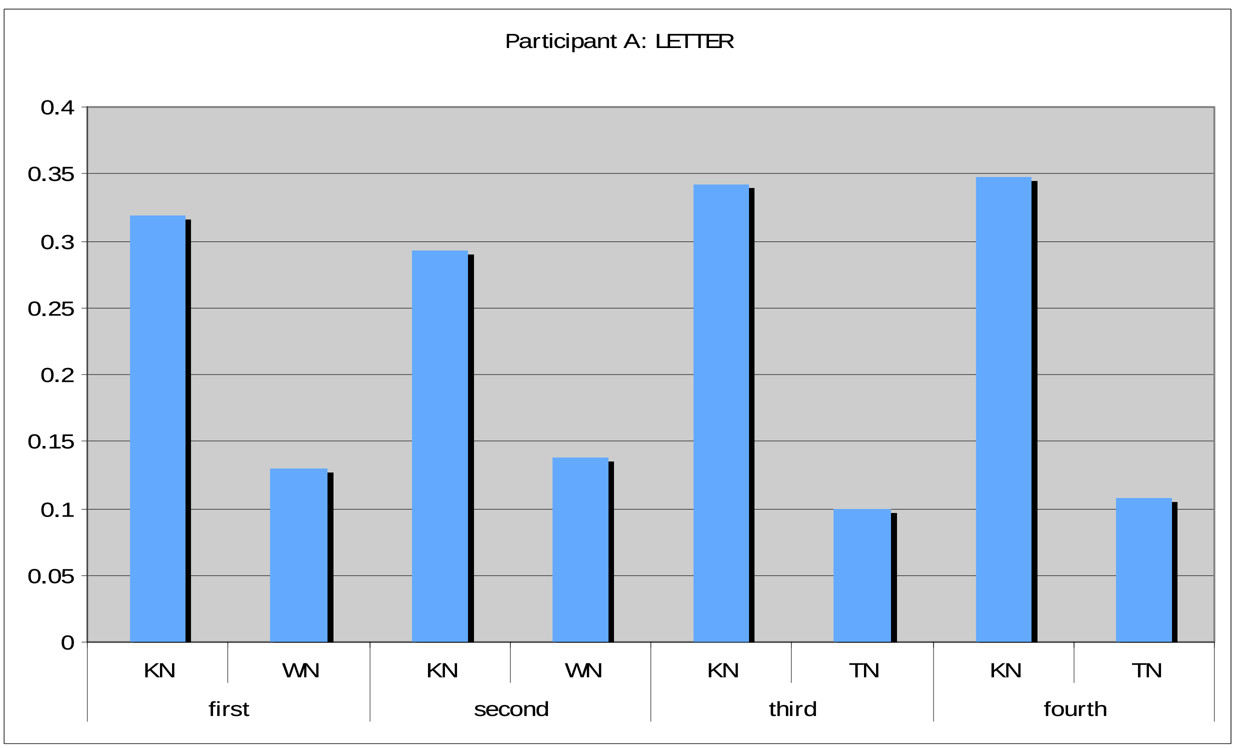
N.1.11 Participant 6

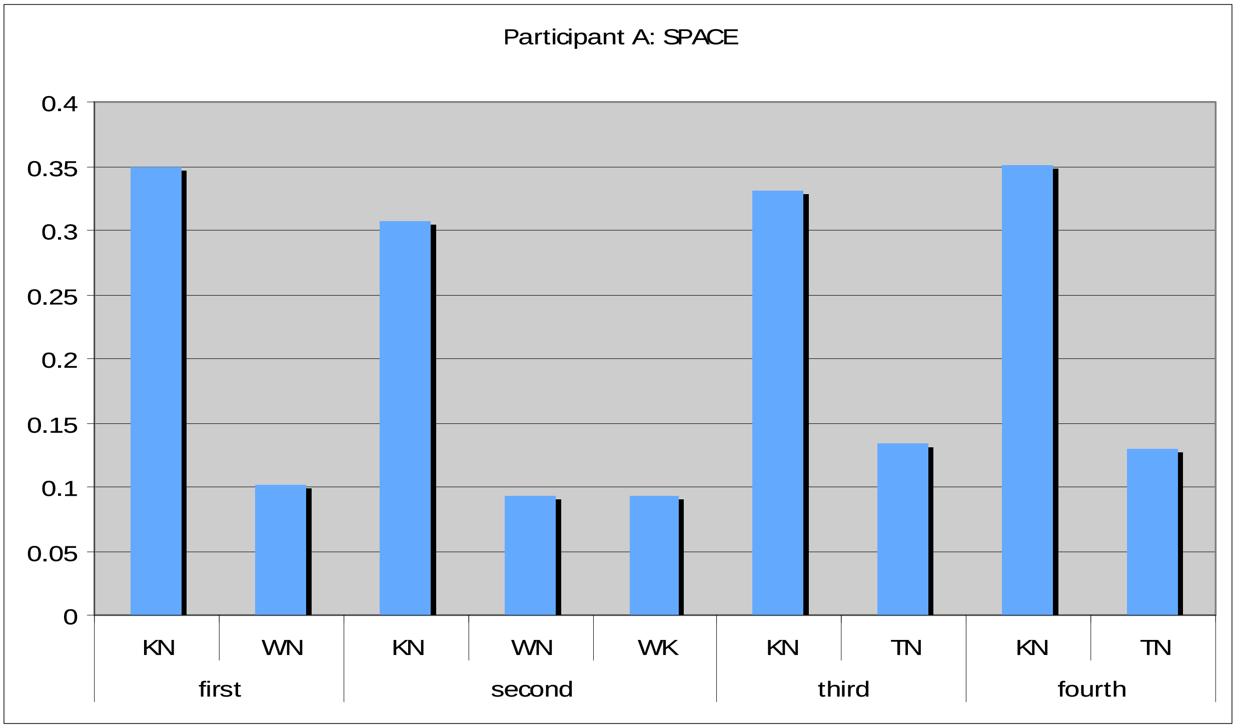
	presented	transcribed	wp list	keyboard	outside	none
presented	0	**-4.619**	0.245	**-4.733**	**14.287**	**-6.288**
transcribed	**3.875**	0	-1.399	0.797	2.165	**-4.859**
wp list	0.760	-2.477	0	0.611	0.220	0.388
keyboard	**-12.084**	3.427	-2.881	0	-1.449	**7.923**
outside	**7.868**	-2.941	0.761	**15.506**	0	**-16.718**

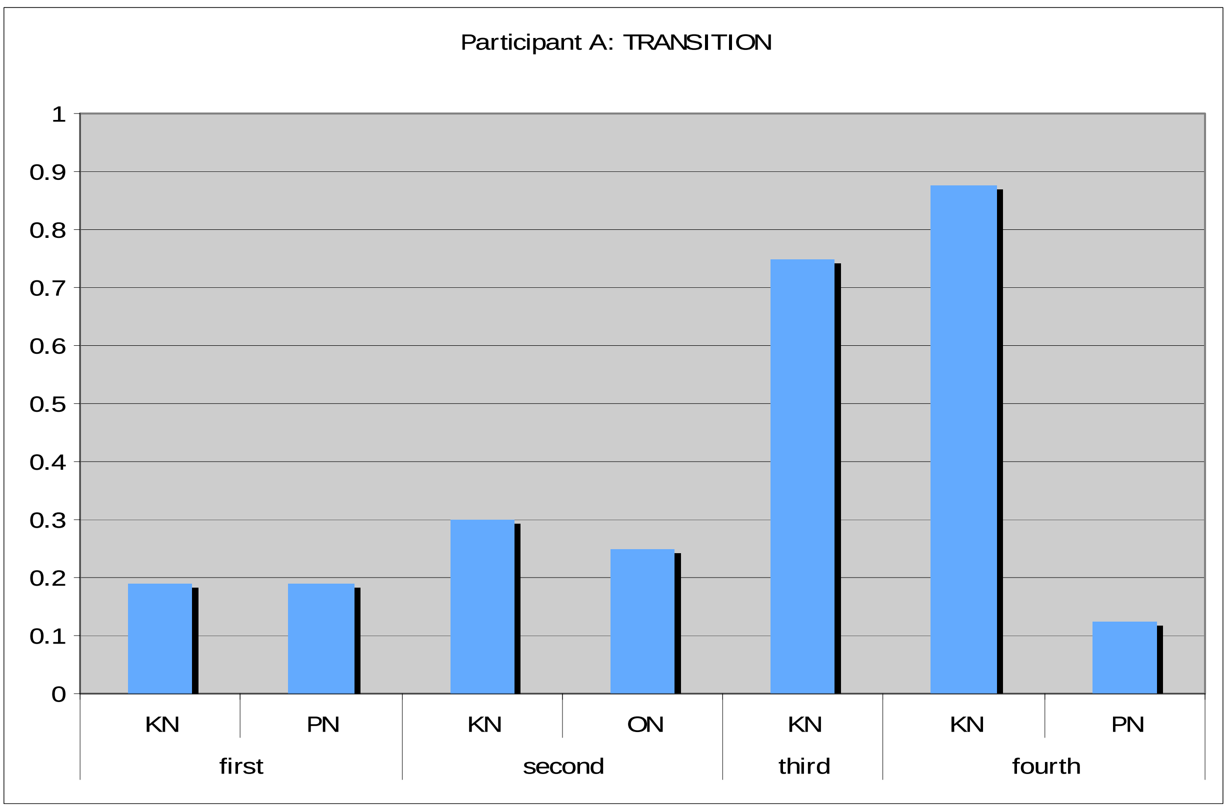
APPENDIX O: WITHIN SUBJECT CONSISTENCY BARCHARTS – WITHIN KEYSTROKE TYPE

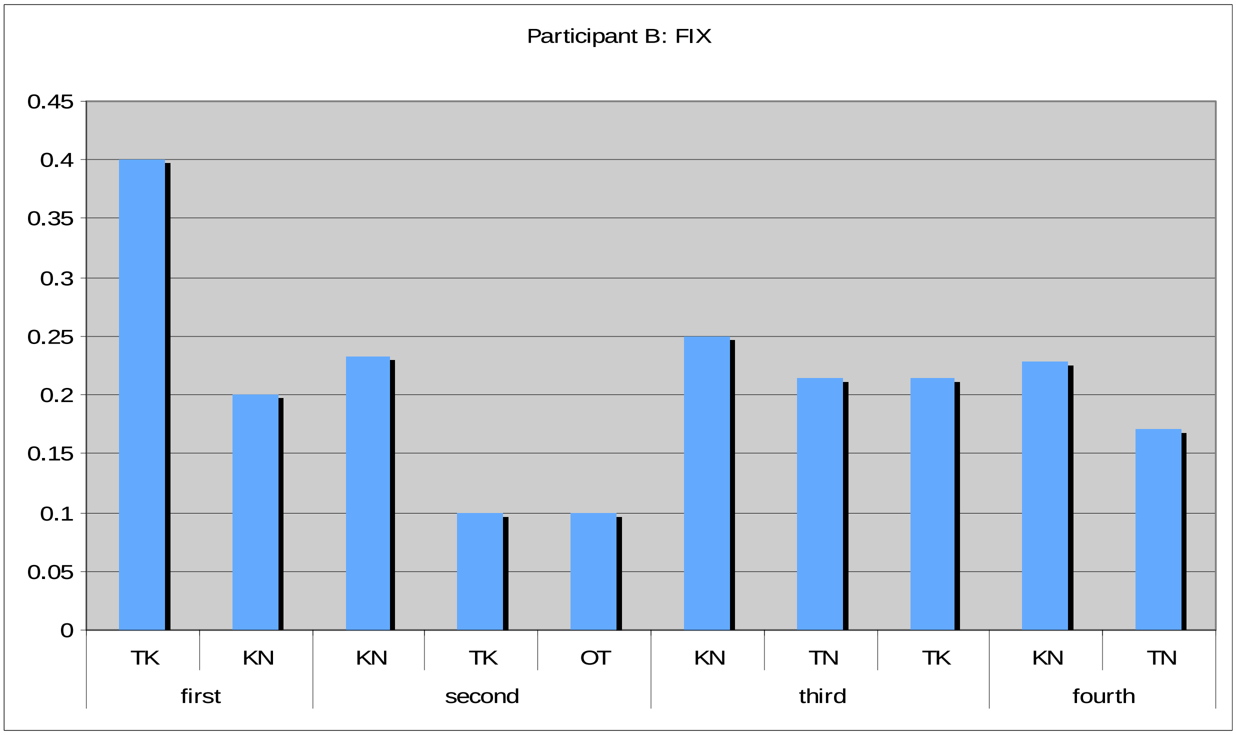


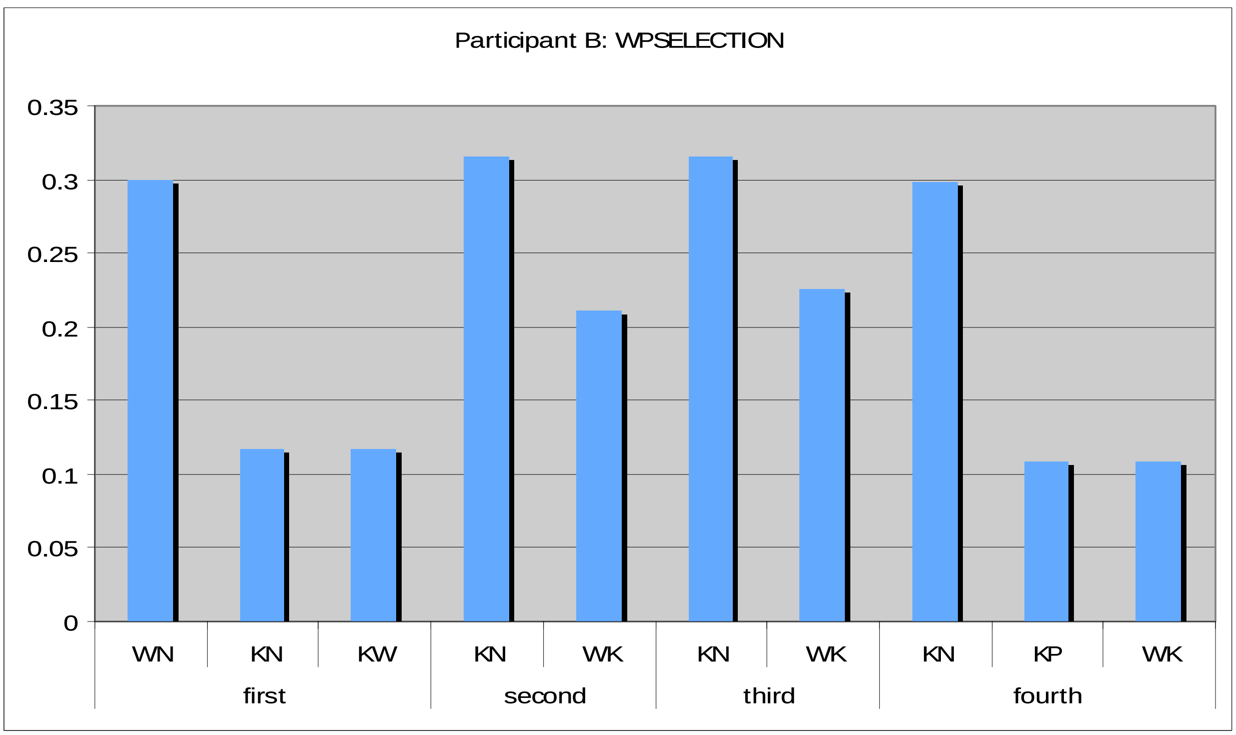

Participant A: WPSELECTION
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
KN
WN
WK
KN
WN
WK
KN
WK
KN
WN
first
second
third
fourth

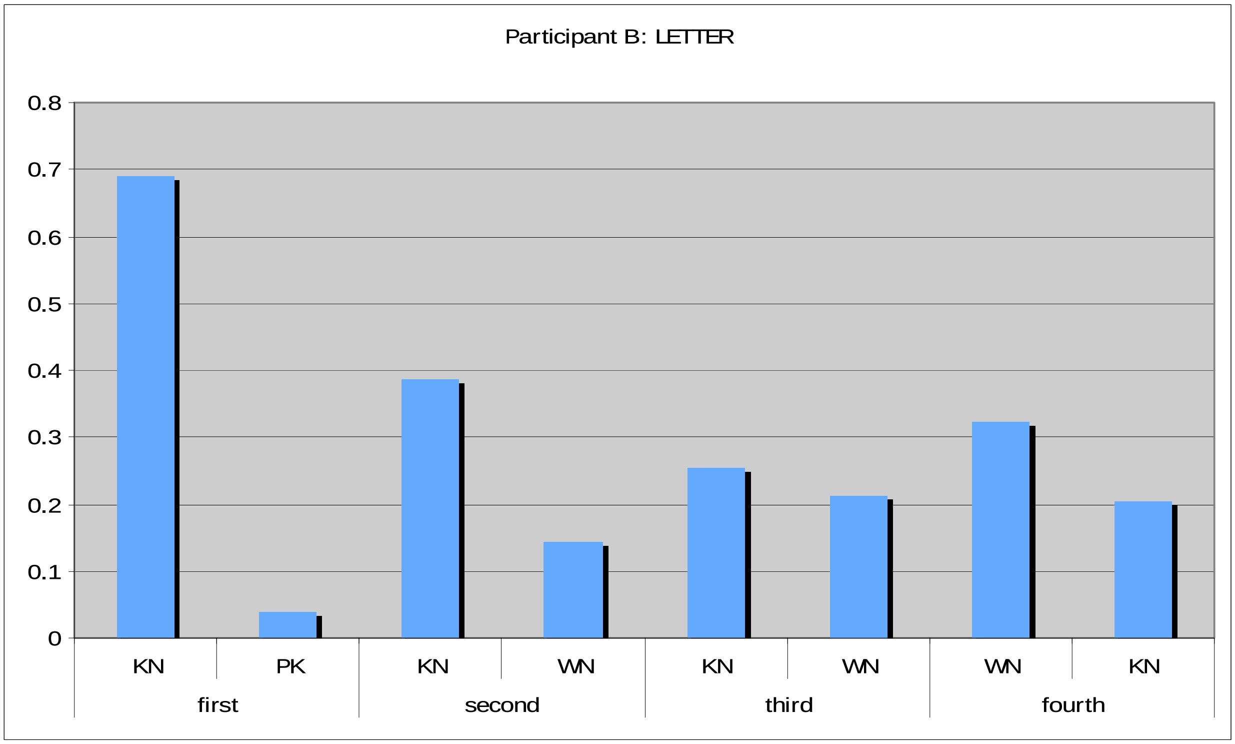

Participant A: LETTER
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
KN
WN
KN
WN
KN
TN
KN
TN
first
second
third
fourth

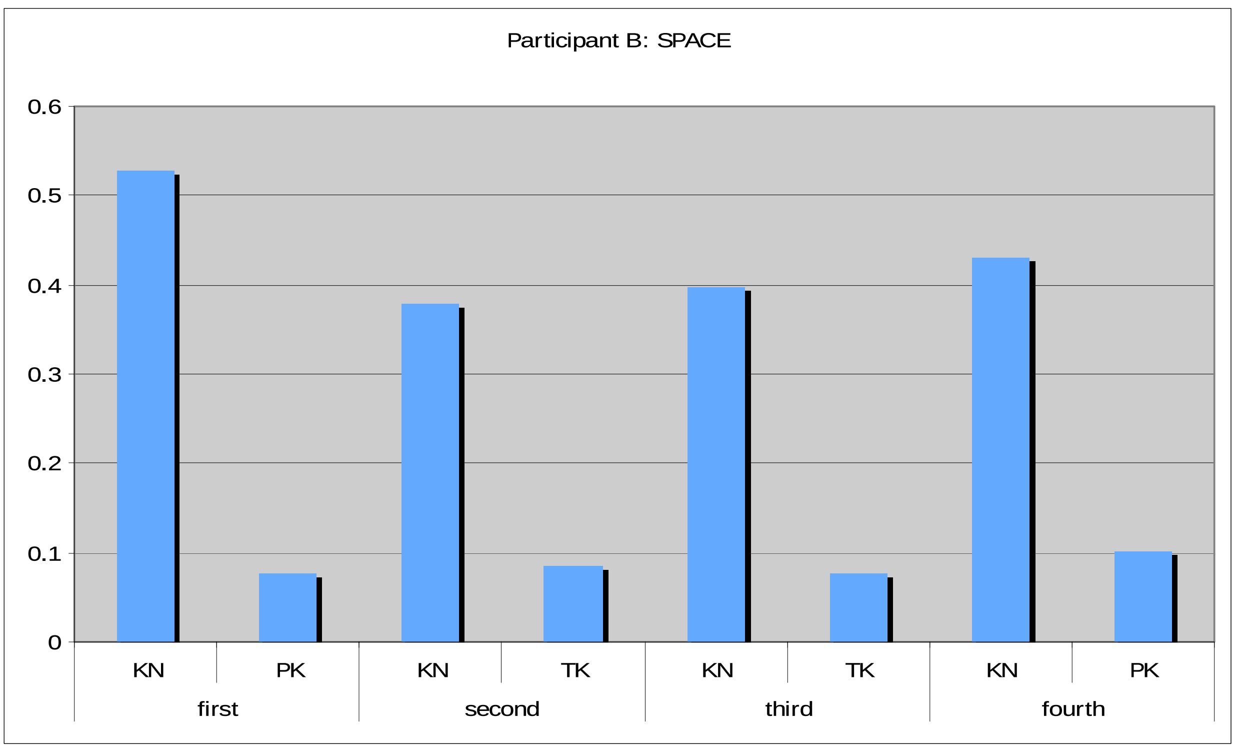

Participant A: SPACE
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
KN
WN
KN
WN
WK
KN
TN
KN
TN
first
second
third
fourth

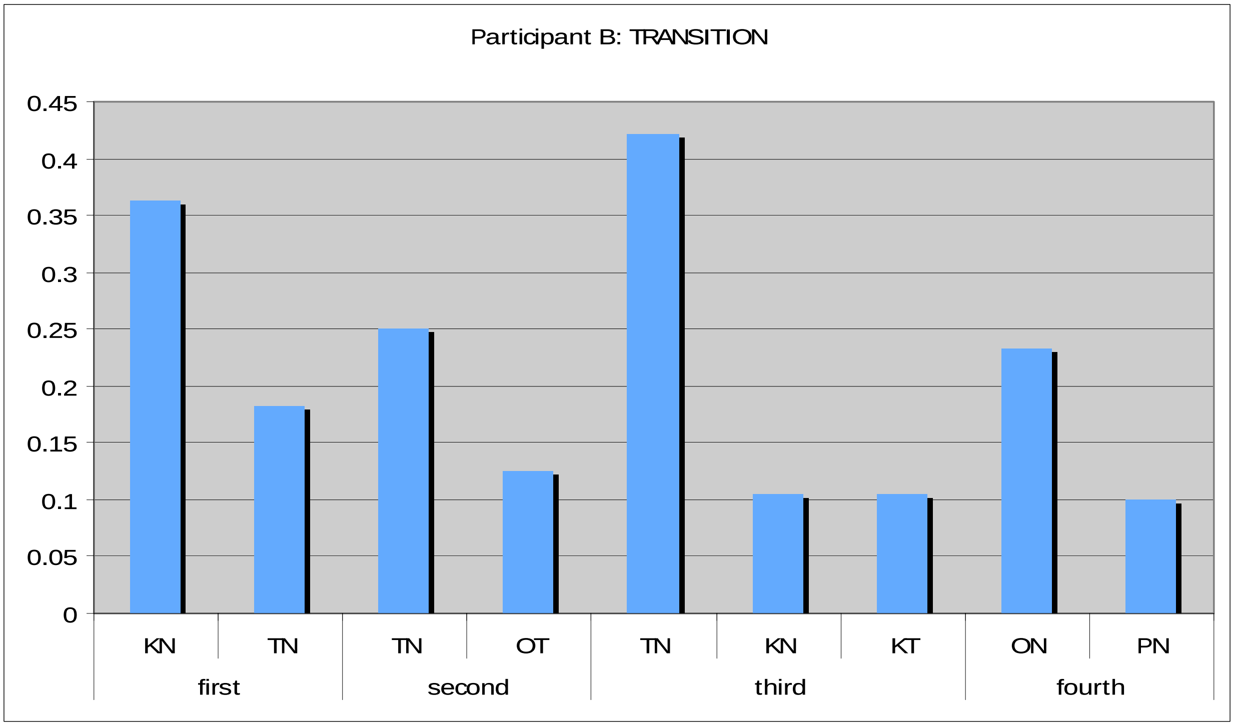

Participant A: TRANSITION
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
KN
PN
KN
ON
KN
KN
PN
first
second
third
fourth

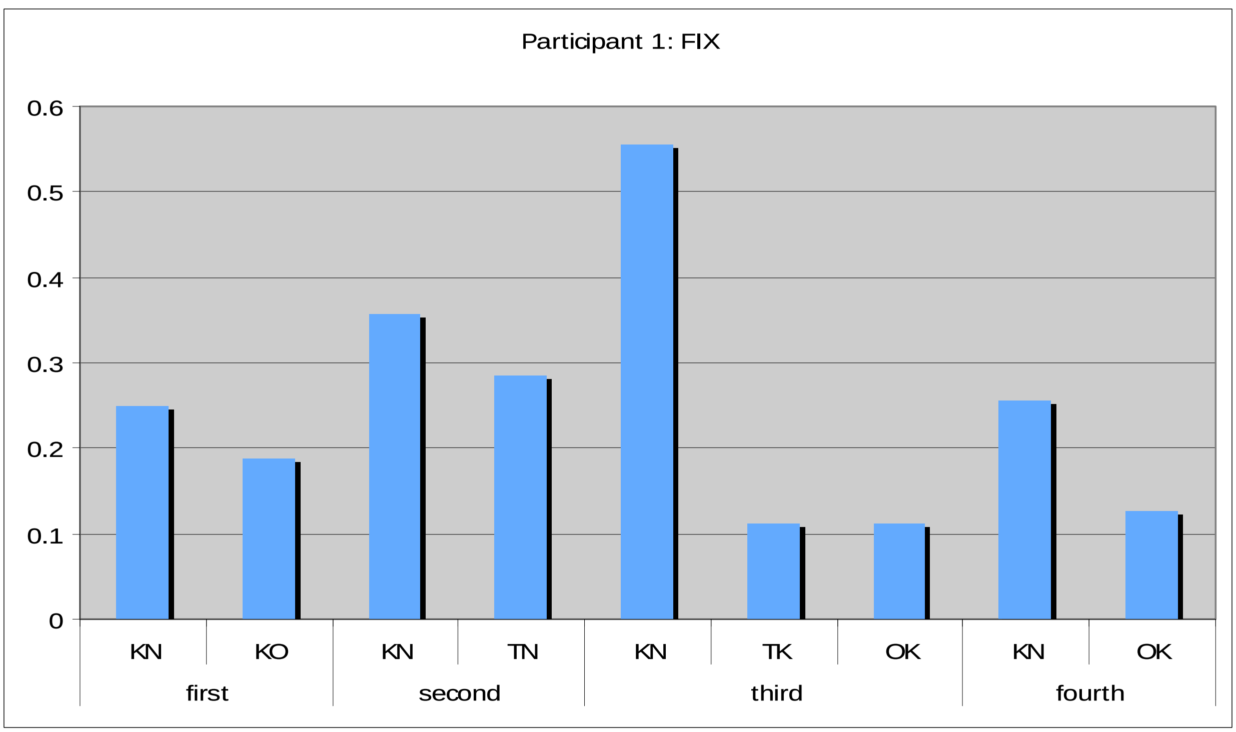

Participant B: FIX
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
TK
KN
KN
TK
OT
KN
TN
TK
KN
TN
first
second
third
fourth

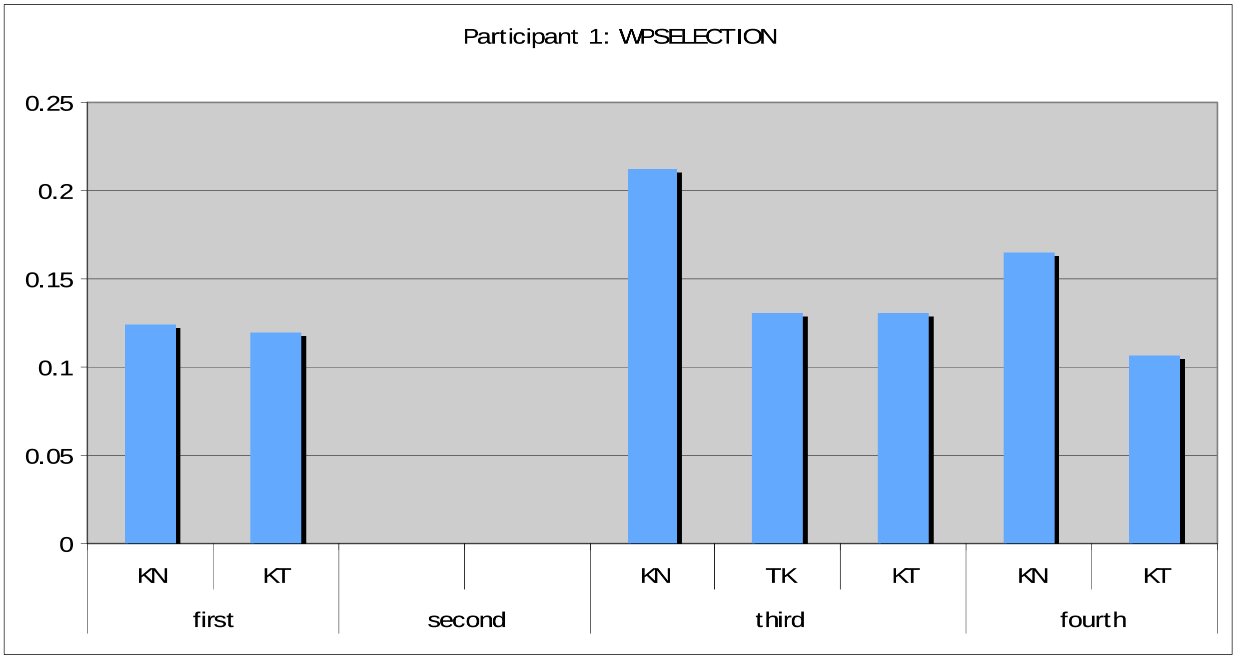

Participant B: WPSELECTION
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
WN
KN
KW
KN
WK
KN
WK
KN
KP
WK
first
second
third
fourth

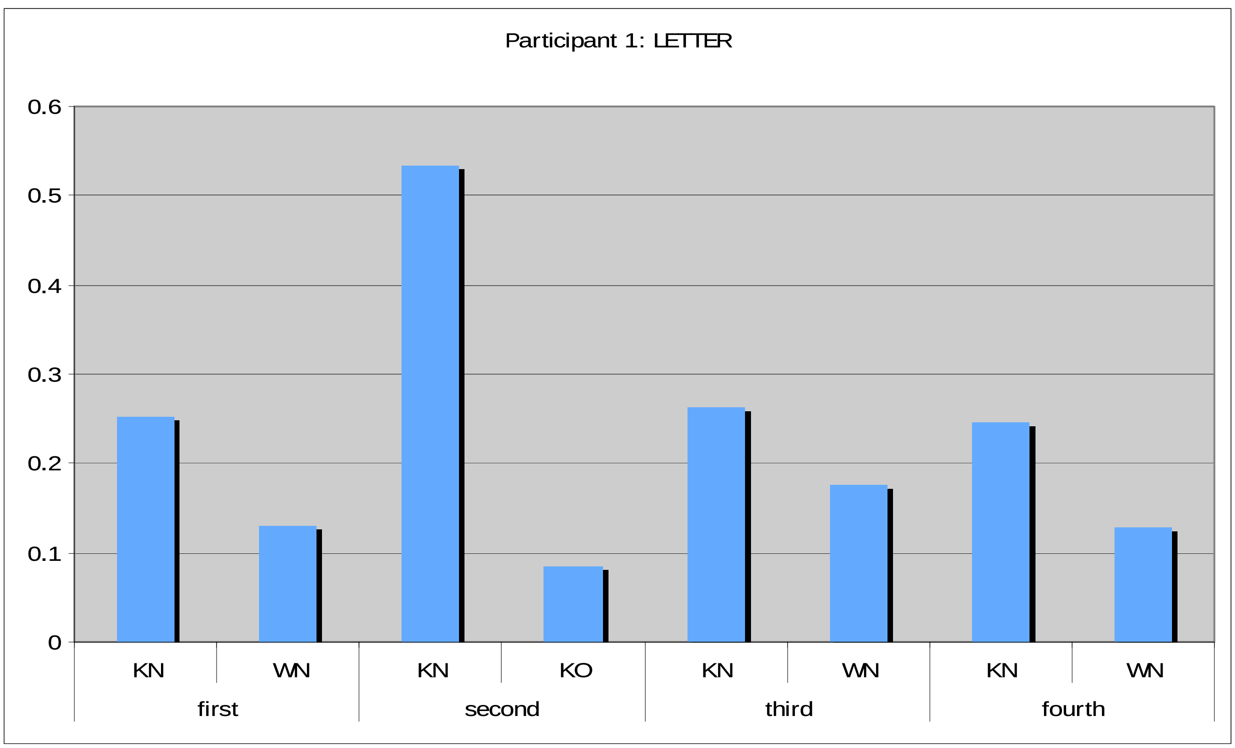

Participant B: LETTER
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
KN
PK
KN
WN
KN
WN
WN
KN
first
second
third
fourth

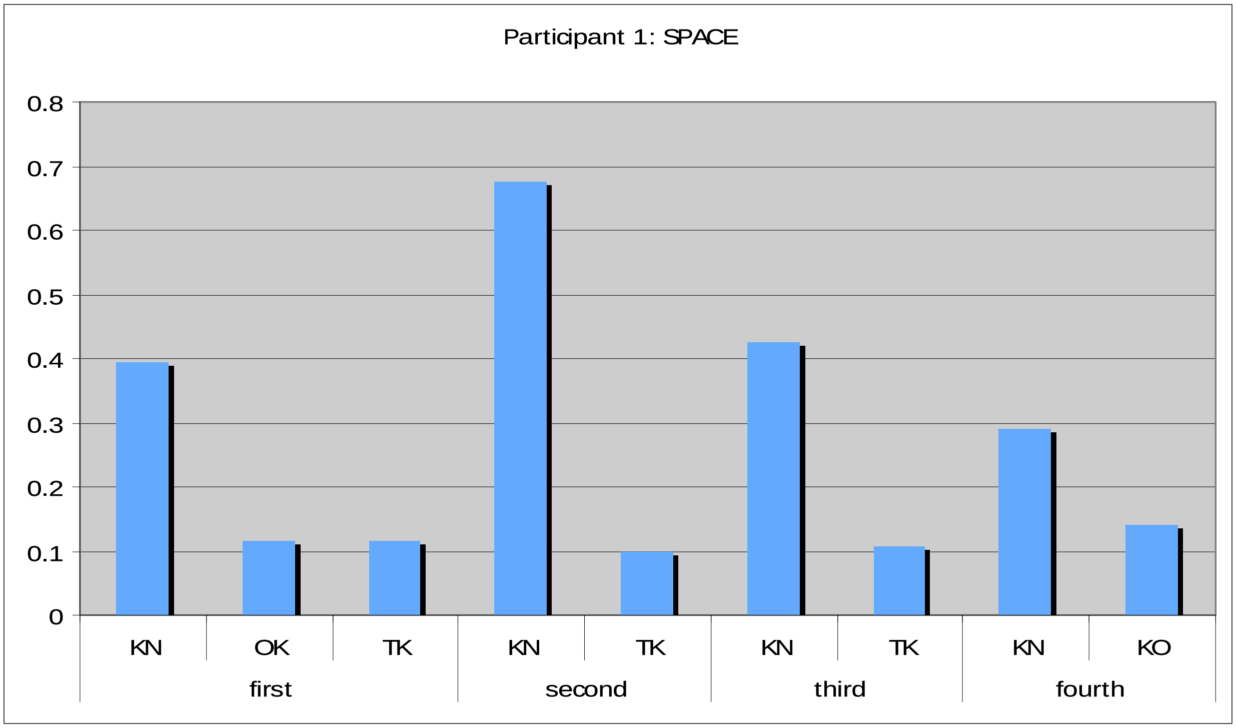

Participant B: SPACE
0.6
0.5
0.4
0.3
0.2
0.1
0
KN
PK
KN
TK
KN
TK
KN
PK
first
second
third
fourth

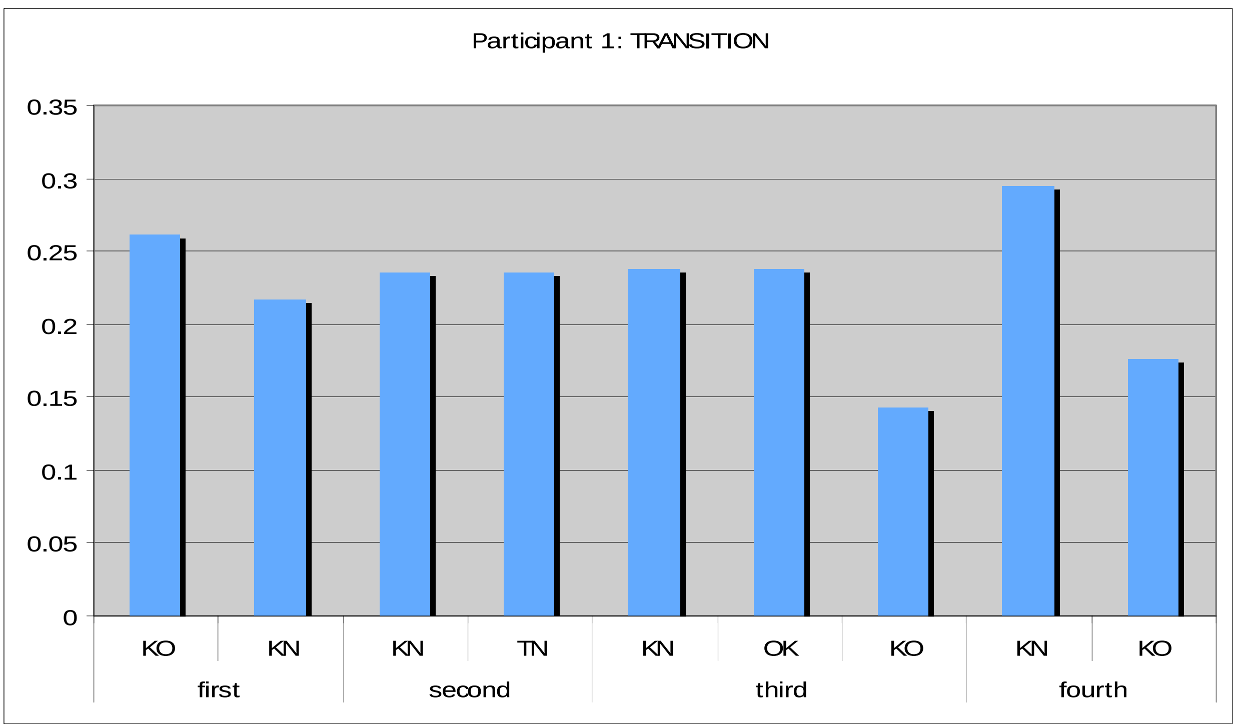

Participant B: TRANSITION
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
KN
TN
TN
OT
TN
KN
KT
ON
PN
first
second
third
fourth

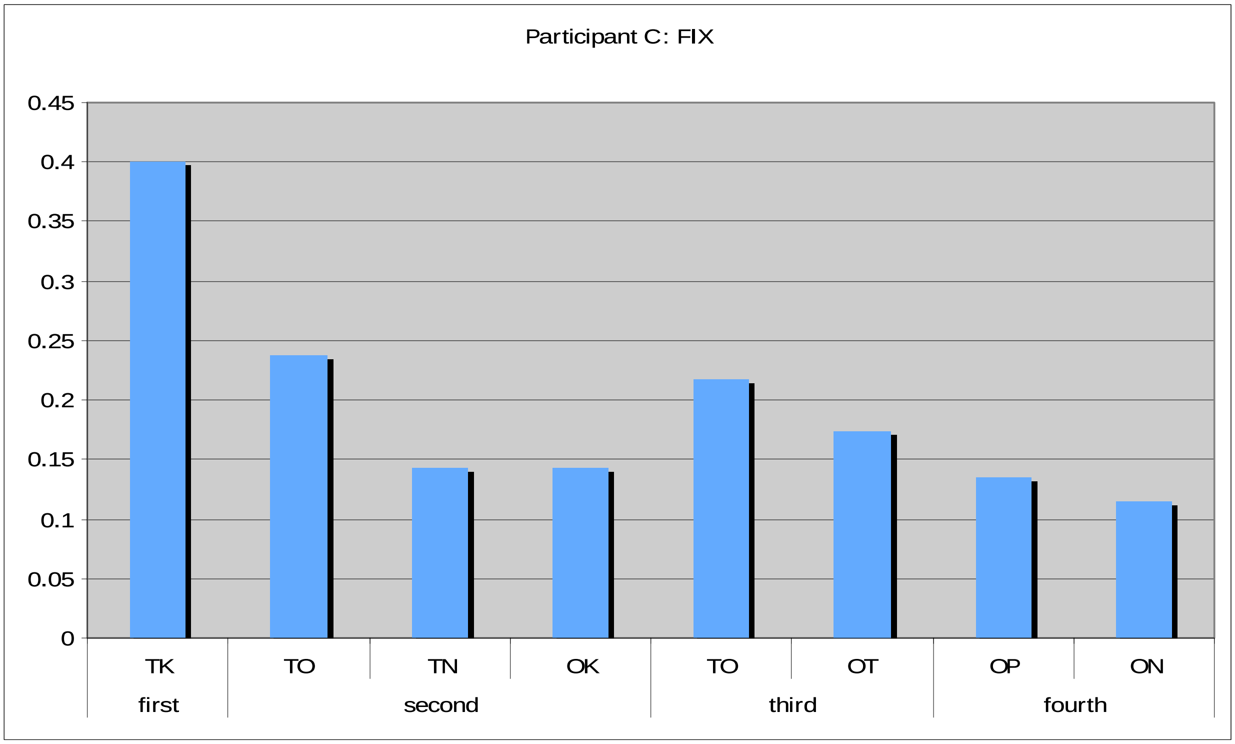

Participant 1: FIX
0.6
0.5
0.4
0.3
0.2
0.1
0
KN
KO
KN
TN
KN
TK
OK
KN
OK
first
second
third
fourth

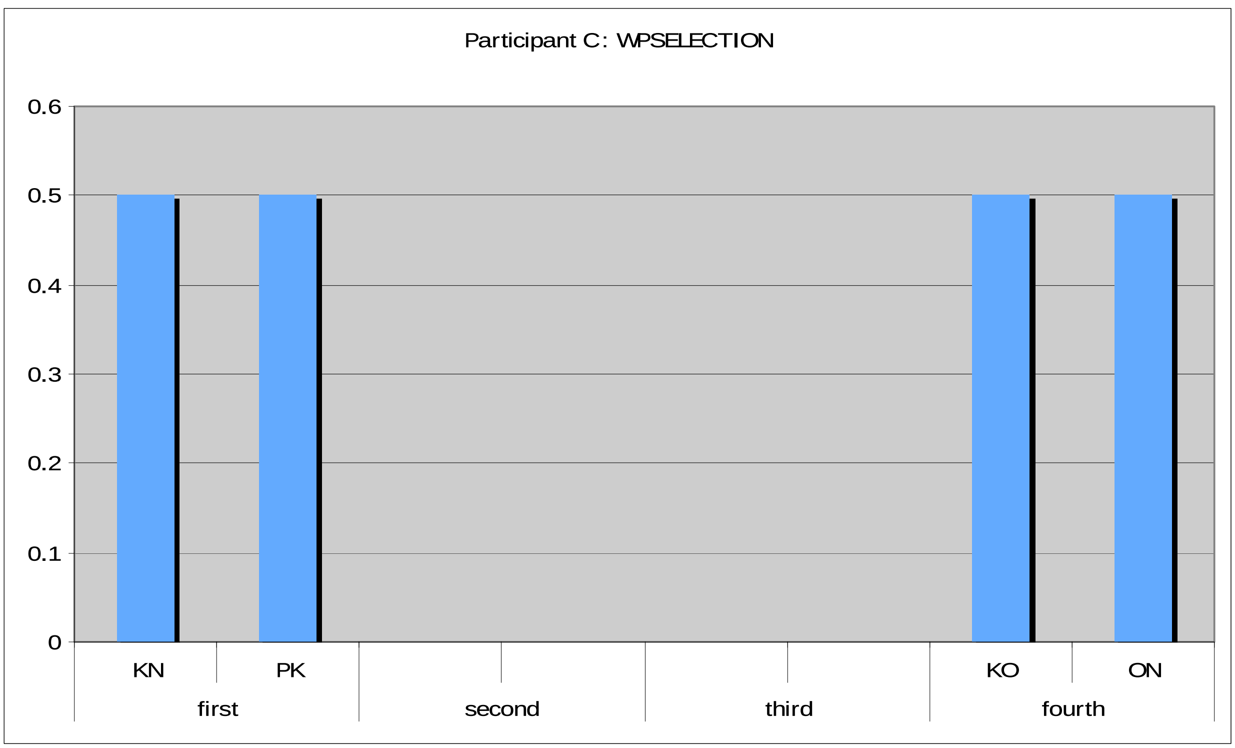

Participant 1: WPSELECTION
0.25
0.2
0.15
0.1
0.05
0
KN
KT
KN
TK
KT
KN
KT
first
second
third
fourth

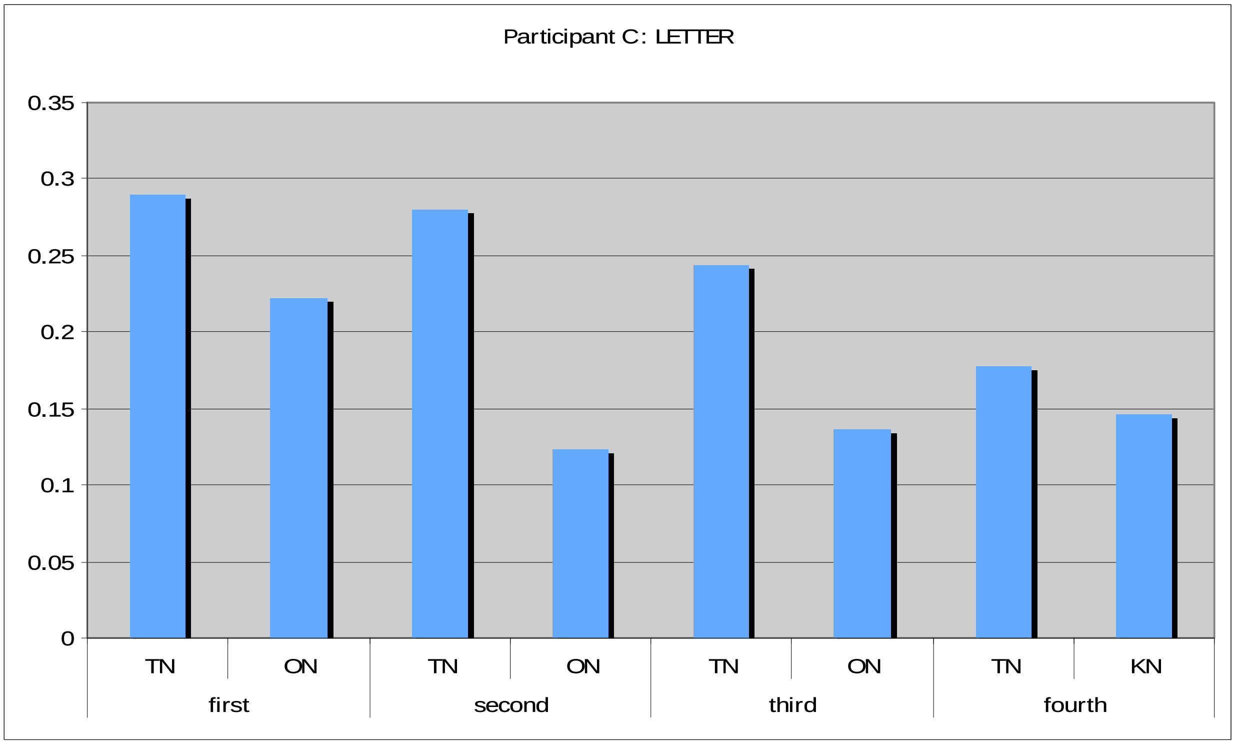

Participant 1: LETTER
0.6
0.5
0.4
0.3
0.2
0.1
0
KN
WN
KN
KO
KN
WN
KN
WN
first
second
third
fourth

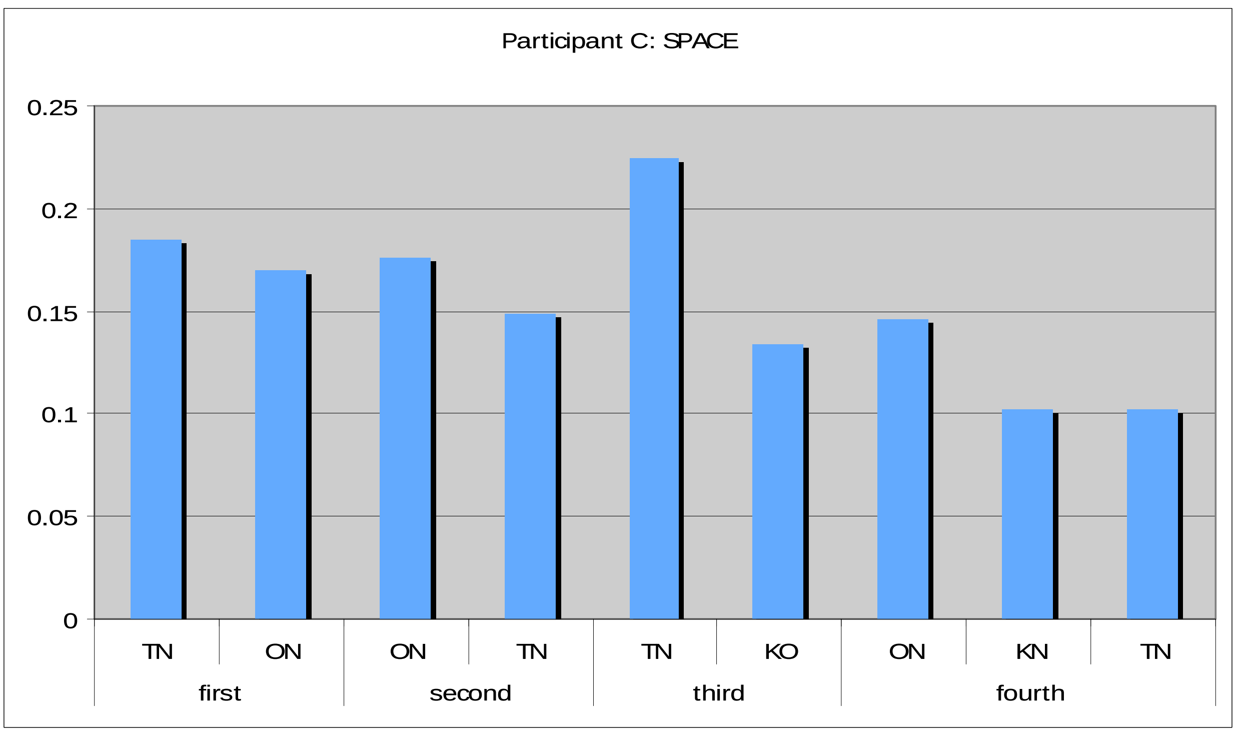

Participant 1: SPACE
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
KN
OK
TK
KN
TK
KN
TK
KN
KO
first
second
third
fourth

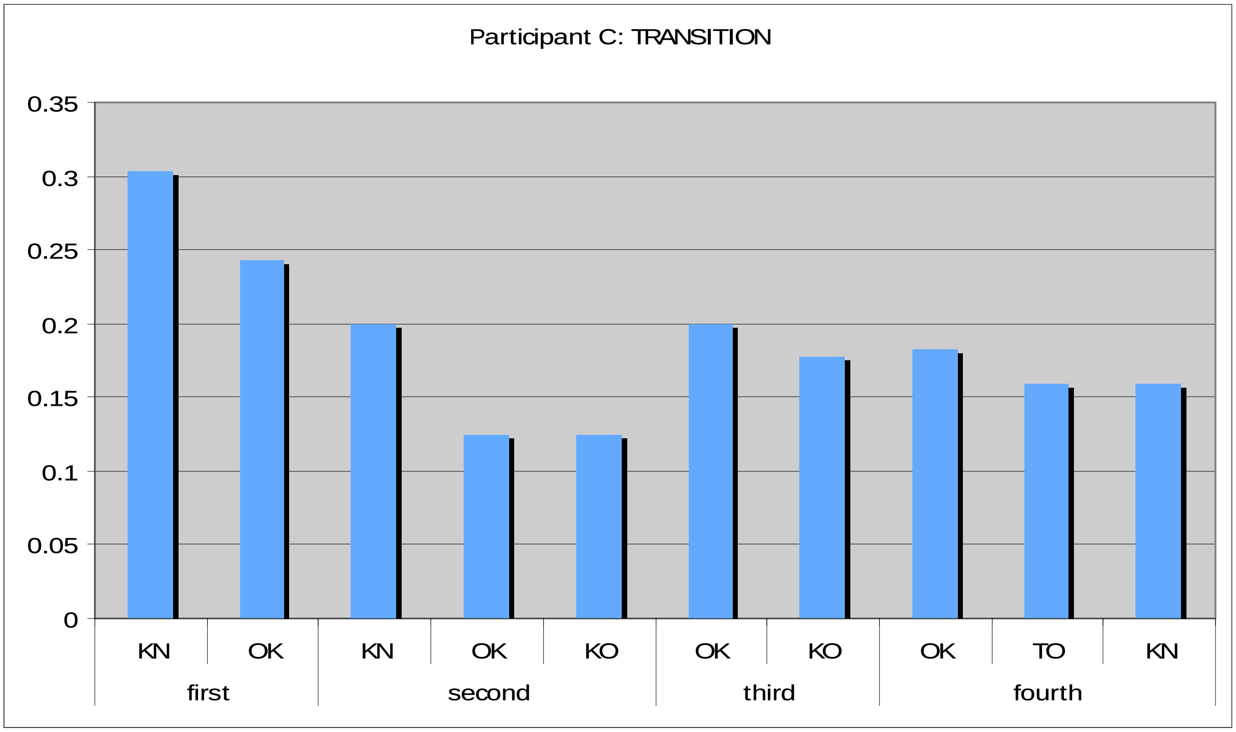

Participant 1: TRANSITION
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
KO
KN
KN
TN
KN
OK
KO
KN
KO
first
second
third
fourth

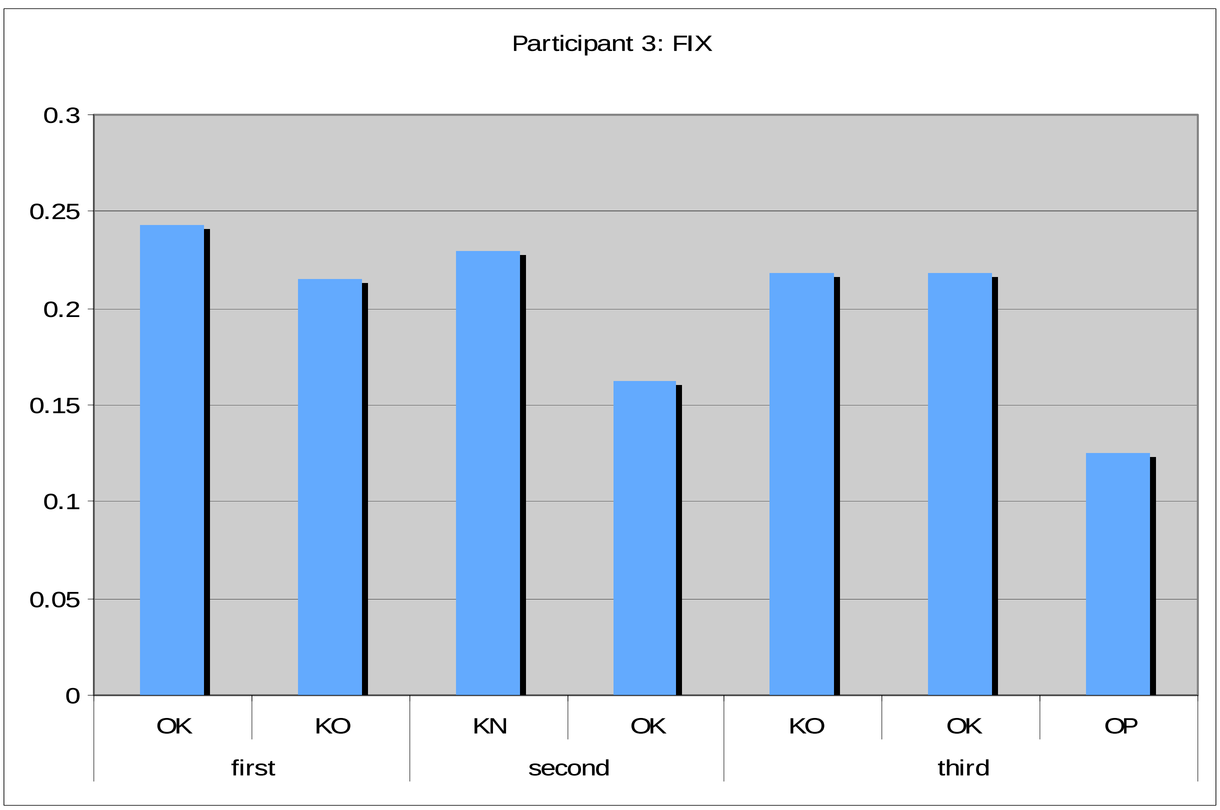

Participant C: FIX
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
TK
TO
TN
OK
TO
OT
OP
ON
first
second
third
fourth

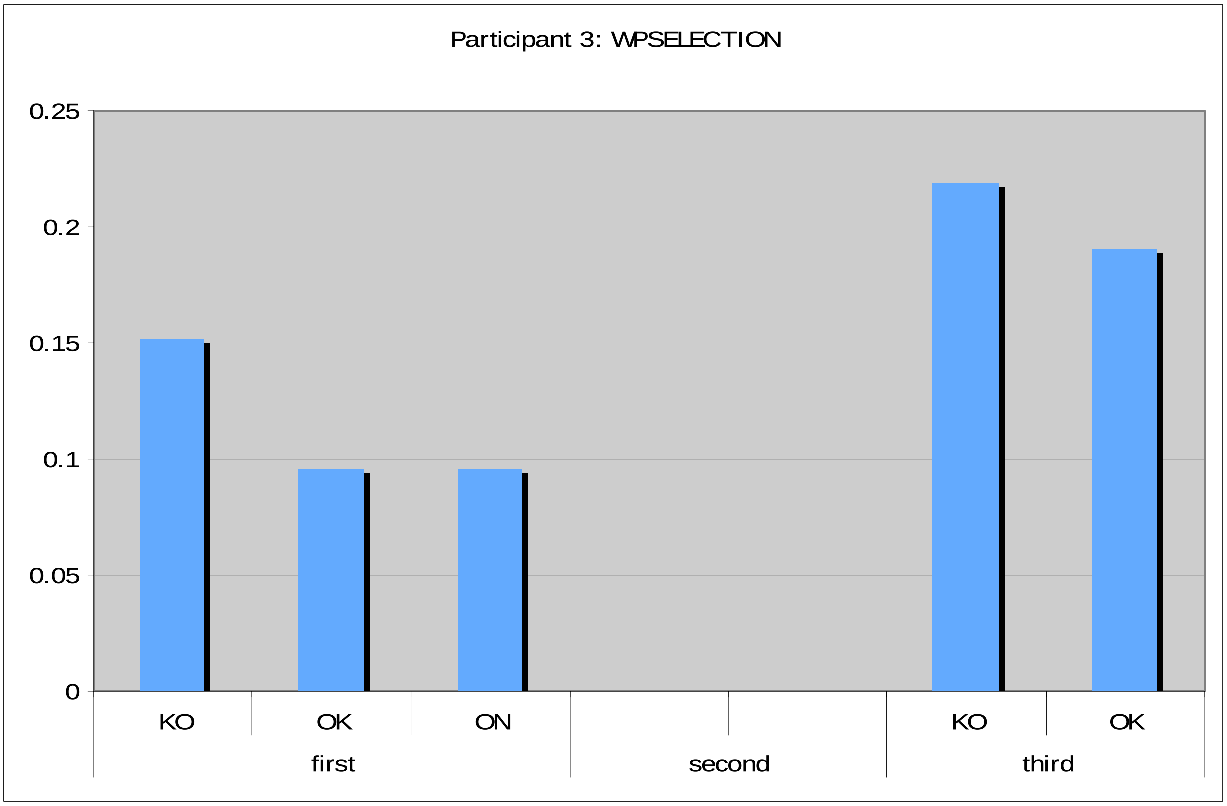

Participant C: WPSELECTION
0.6
0.5
0.4
0.3
0.2
0.1
0
KN
PK
KO
ON
first
second
third
fourth

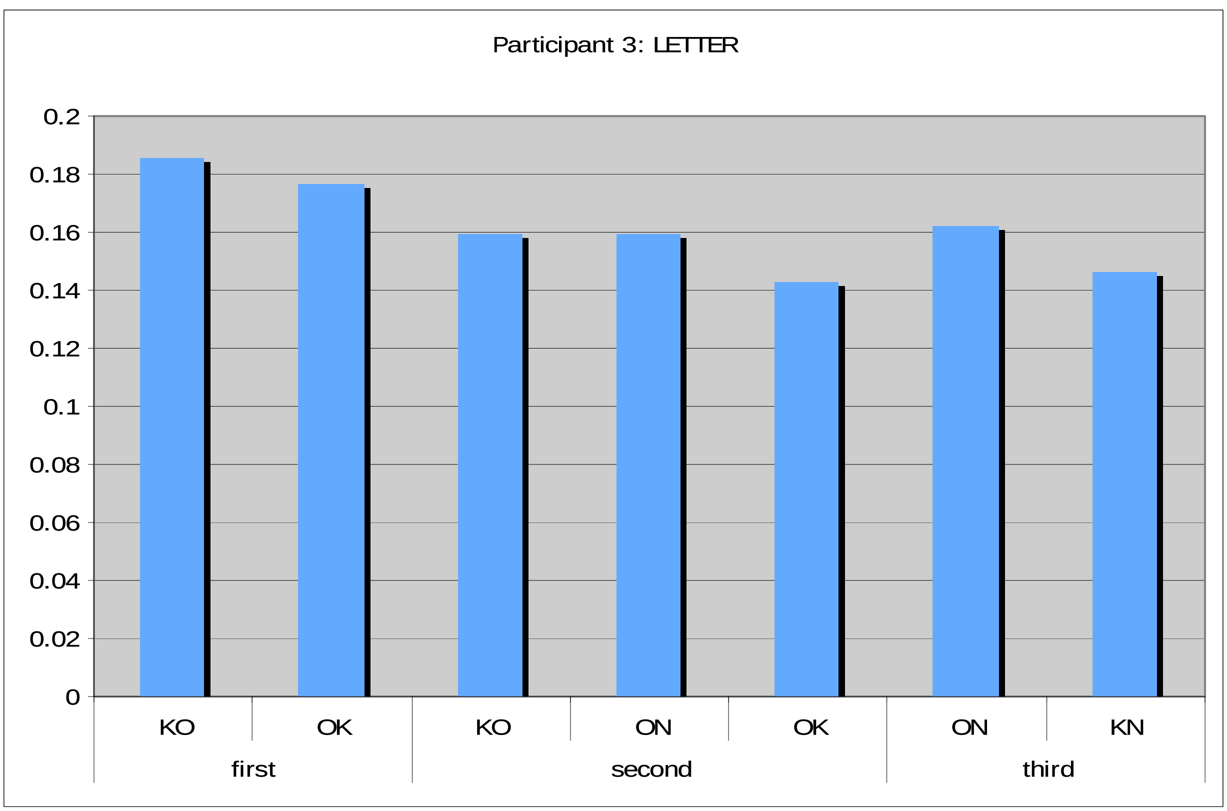

Participant C: LETTER
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
TN
ON
TN
ON
TN
ON
TN
KN
first
second
third
fourth

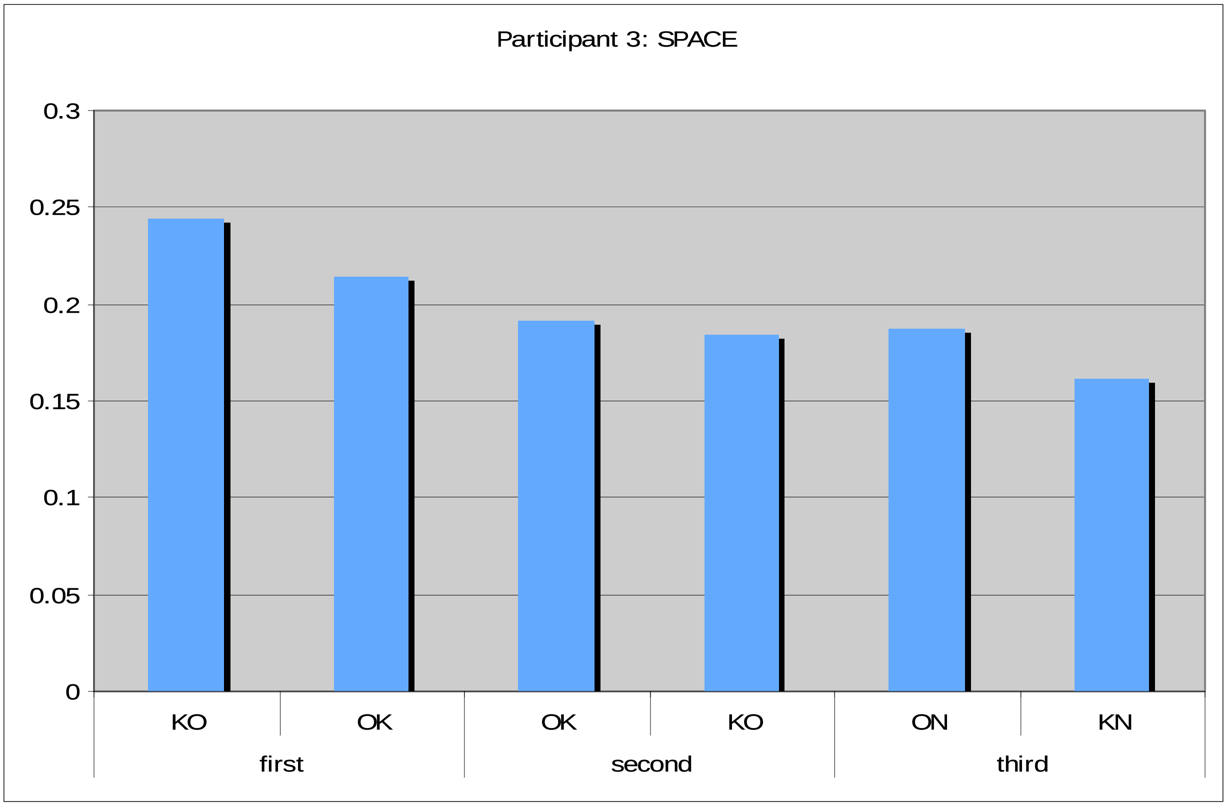

Participant C: SPACE
0.25
0.2
0.15
0.1
0.05
0
TN
ON
ON
TN
TN
KO
ON
KN
TN
first
second
third
fourth

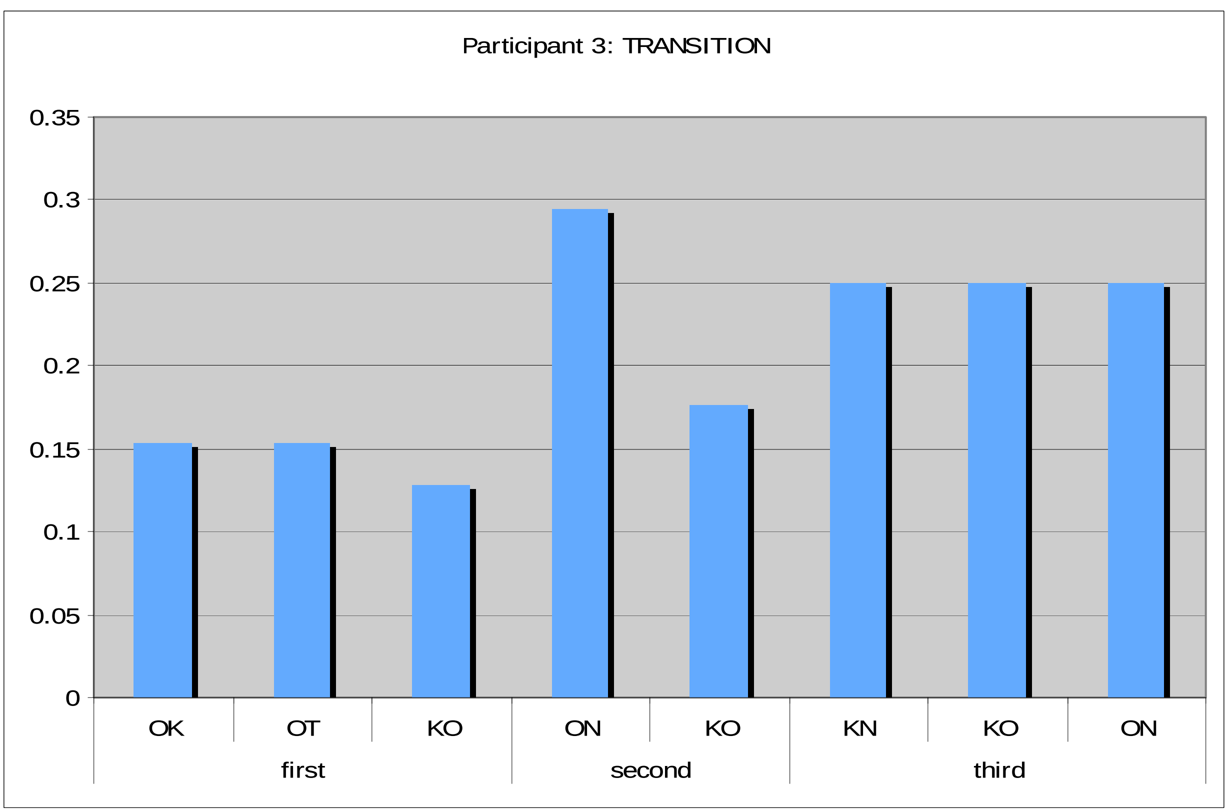

Participant C: TRANSITION
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
KN
OK
KN
OK
KO
OK
KO
OK
TO
KN
first
second
third
fourth

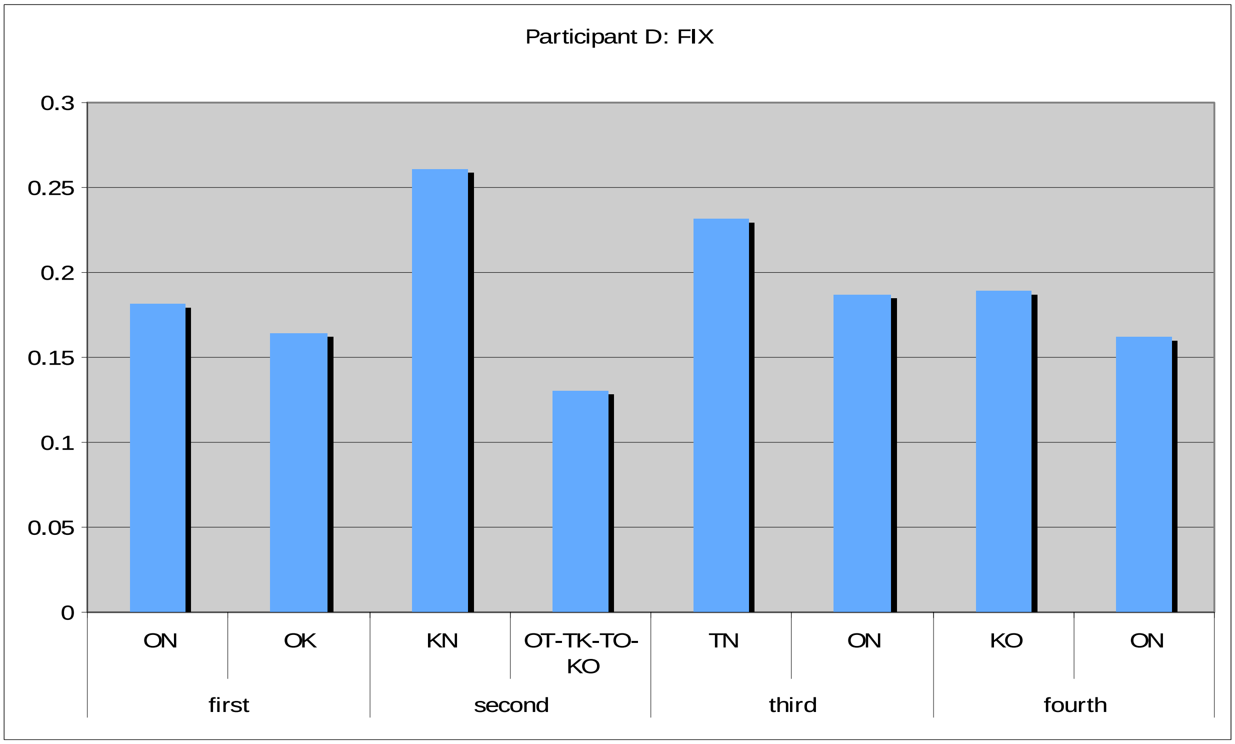

Participant 3: FIX
0.3
0.25
0.2
0.15
0.1
0.05
0
OK
KO
KN
OK
KO
OK
OP
first
second
third

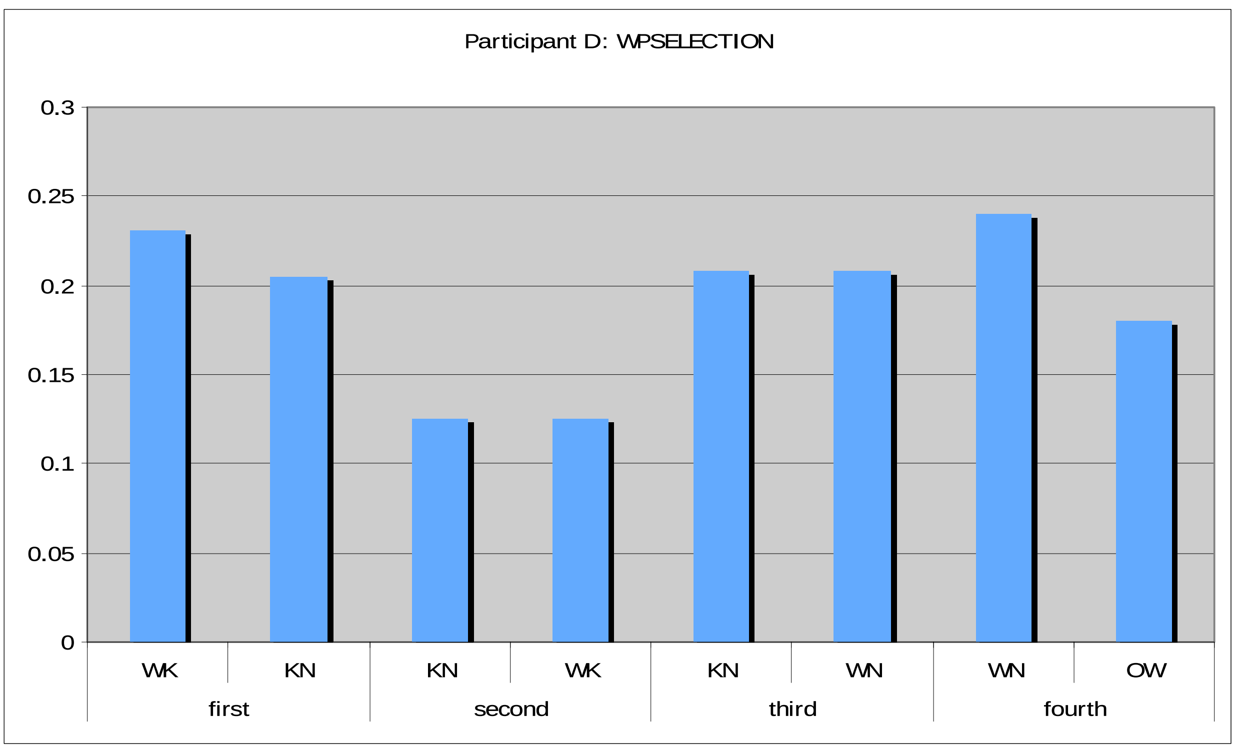

Participant 3: WPSELECTION
0.25
0.2
0.15
0.1
0.05
0
KO
OK
ON
KO
OK
first
second
third

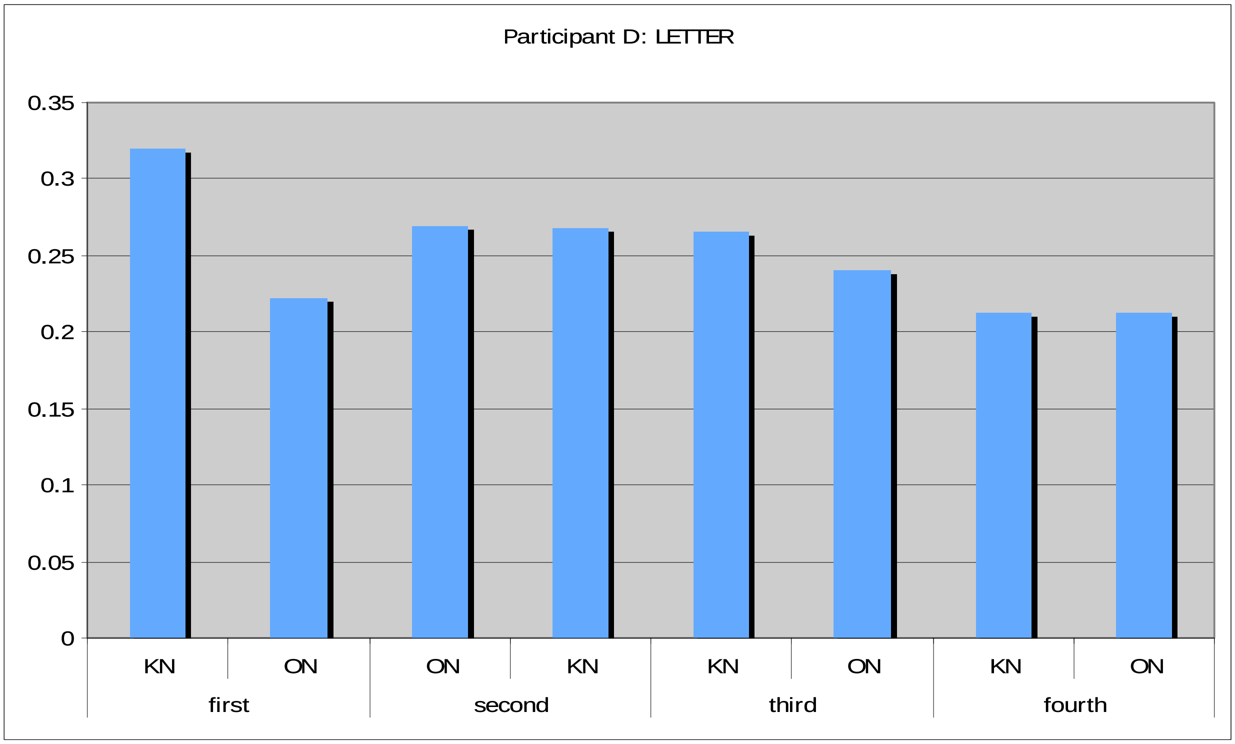

Participant 3: LETTER
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
KO
OK
KO
ON
OK
ON
KN
first
second
third

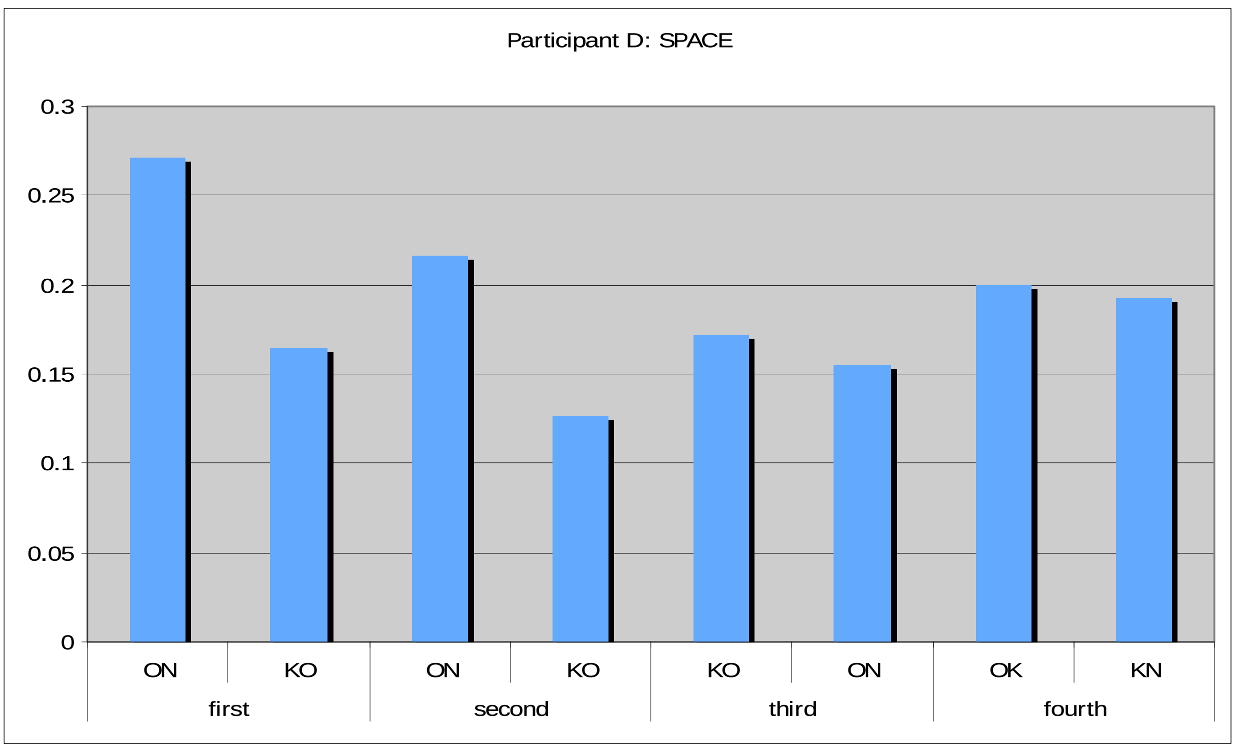

Participant 3: SPACE
0.3
0.25
0.2
0.15
0.1
0.05
0
KO
OK
OK
KO
ON
KN
first
second
third

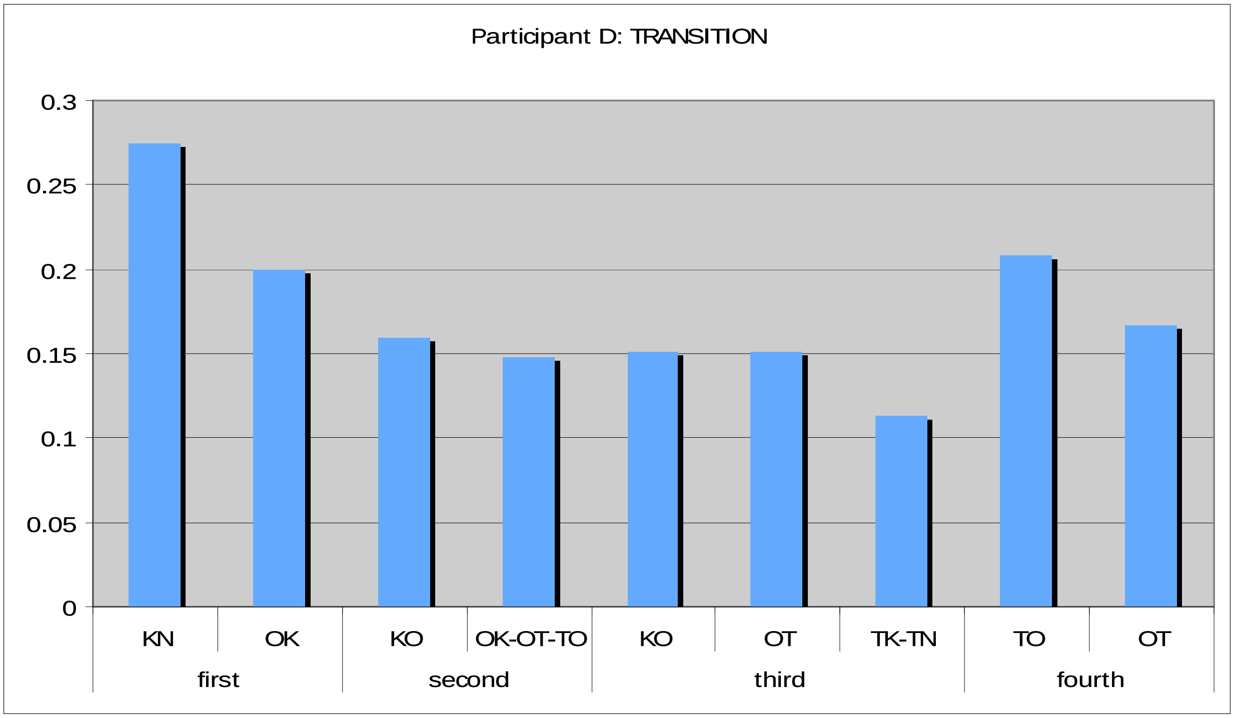

Participant 3: TRANSITION
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
OK
OT
KO
ON
KO
KN
KO
ON
first
second
third

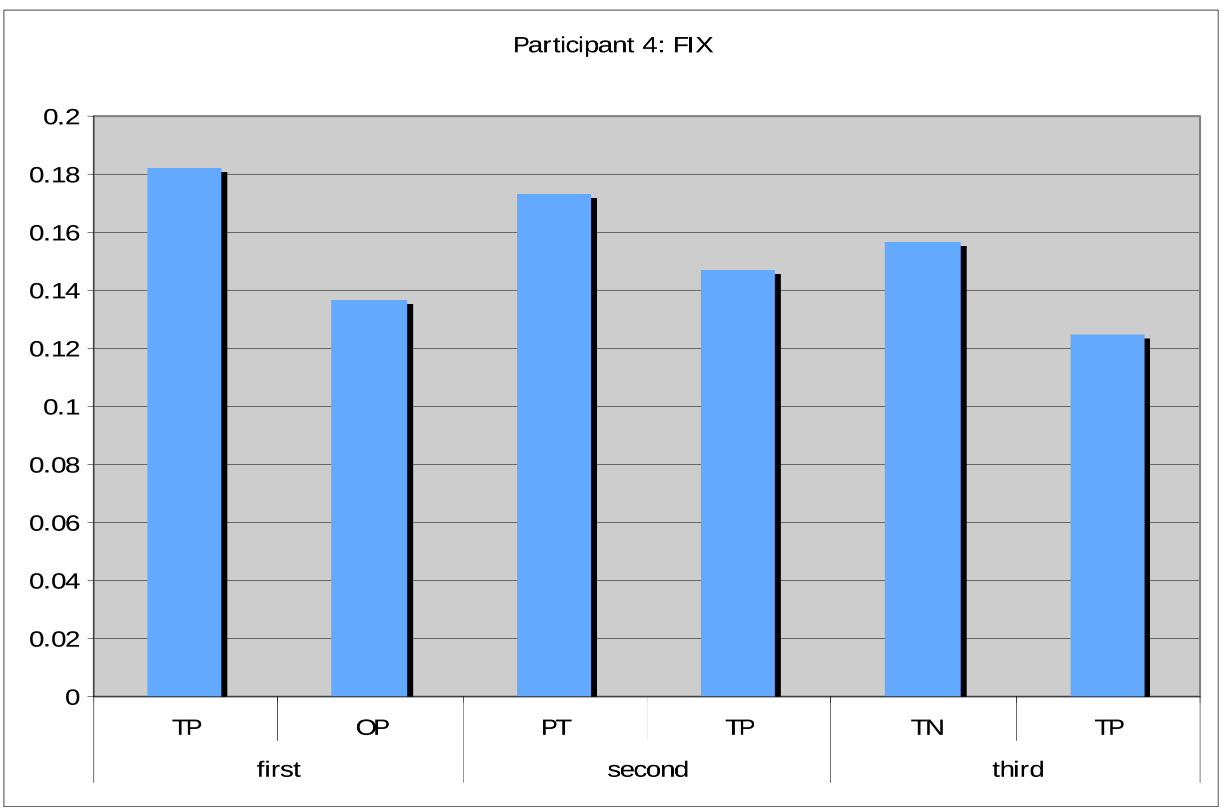

Participant D: FIX
0.3
0.25
0.2
0.15
0.1
0.05
0
ON
OK
KN
OT-TK-TO-KO
TN
ON
KO
ON
first
second
third
fourth

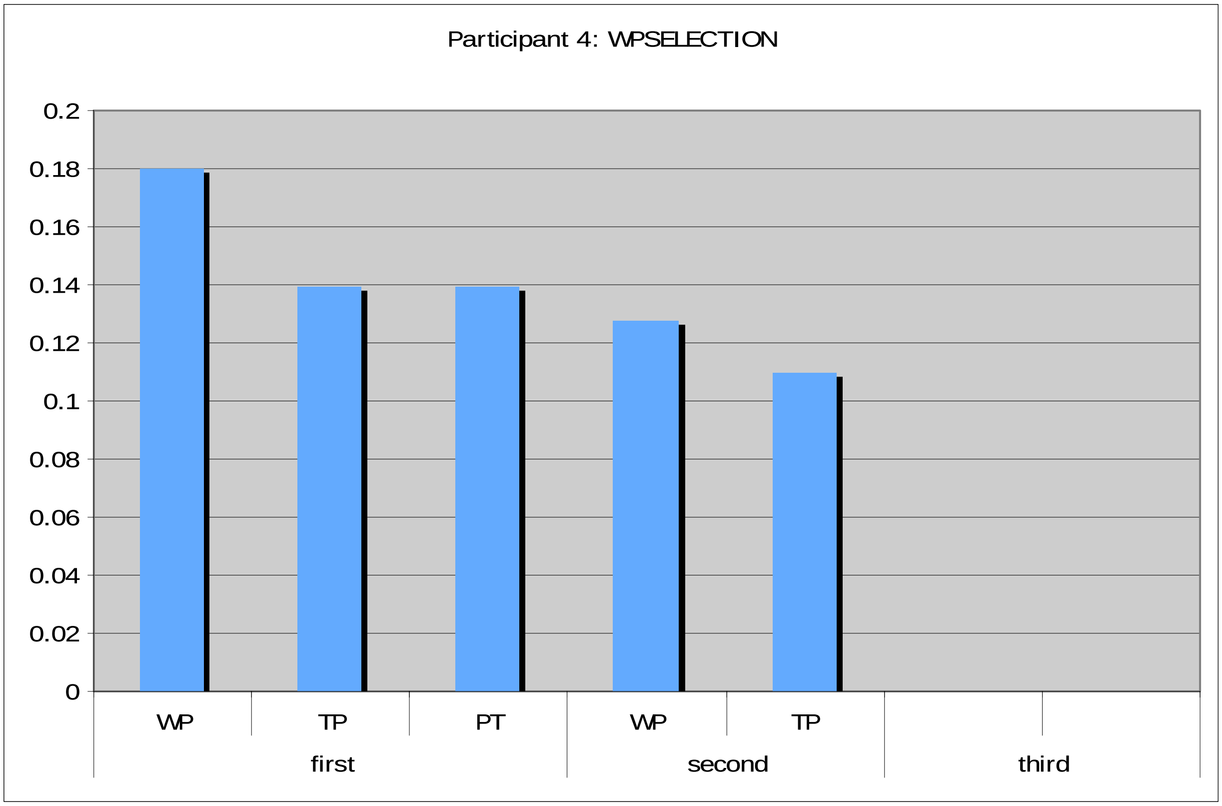

Participant D: WPSELECTION
0.3
0.25
0.2
0.15
0.1
0.05
0
WK
KN
KN
WK
KN
WN
WN
OW
first
second
third
fourth

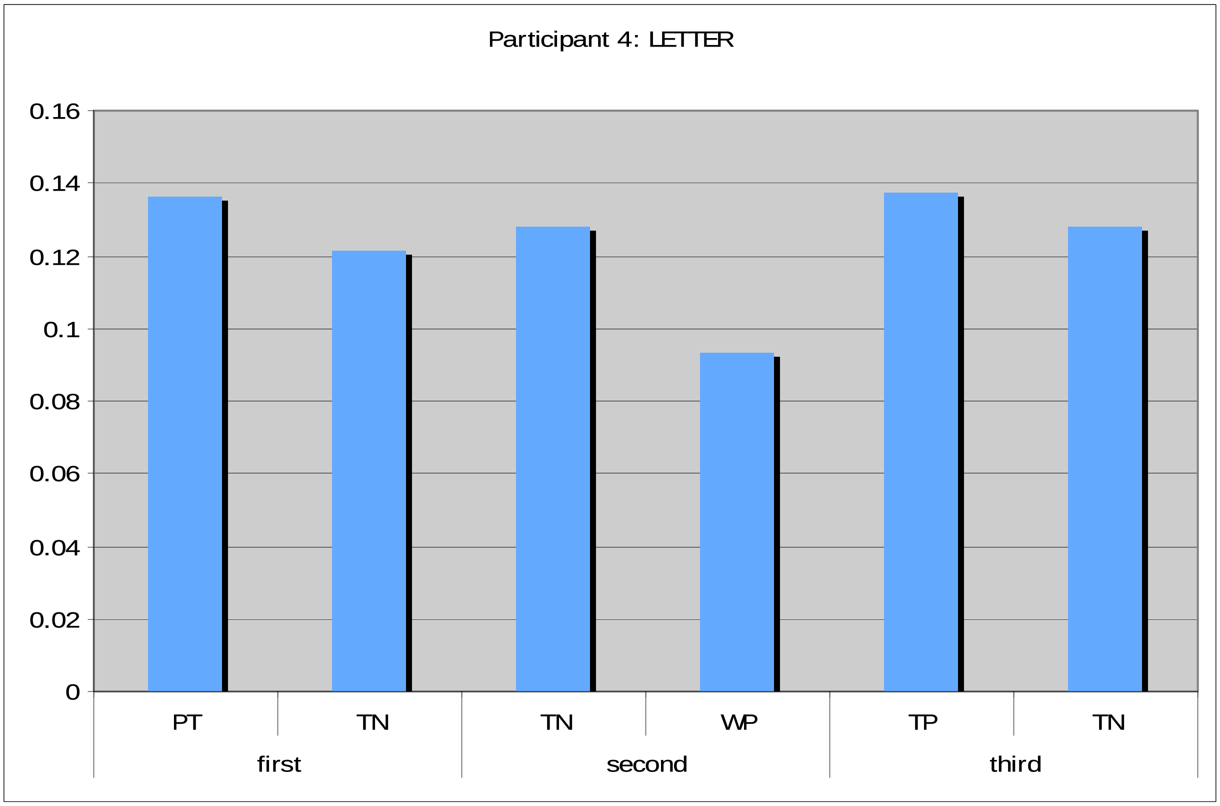

Participant D: LETTER
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
KN
ON
ON
KN
KN
ON
KN
ON
first
second
third
fourth

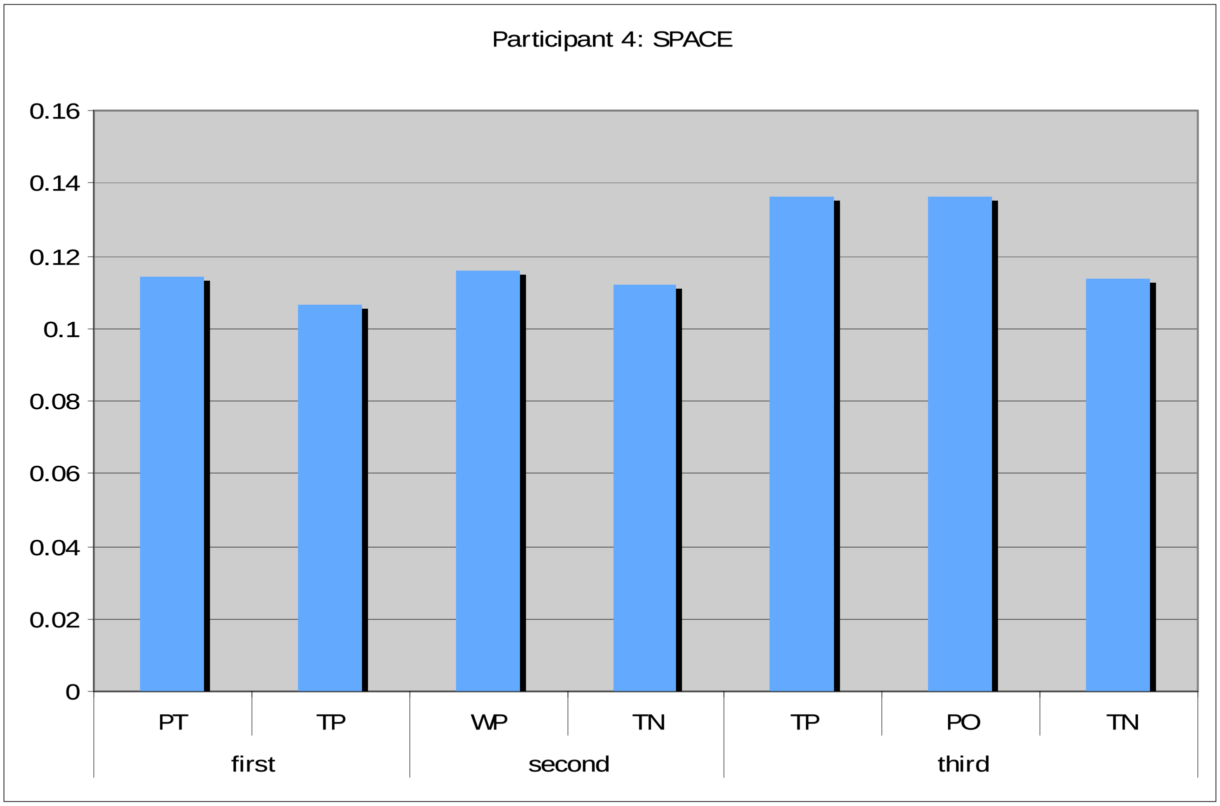

Participant D: SPACE
0.3
0.25
0.2
0.15
0.1
0.05
0
ON
KO
ON
KO
KO
ON
OK
KN
first
second
third
fourth

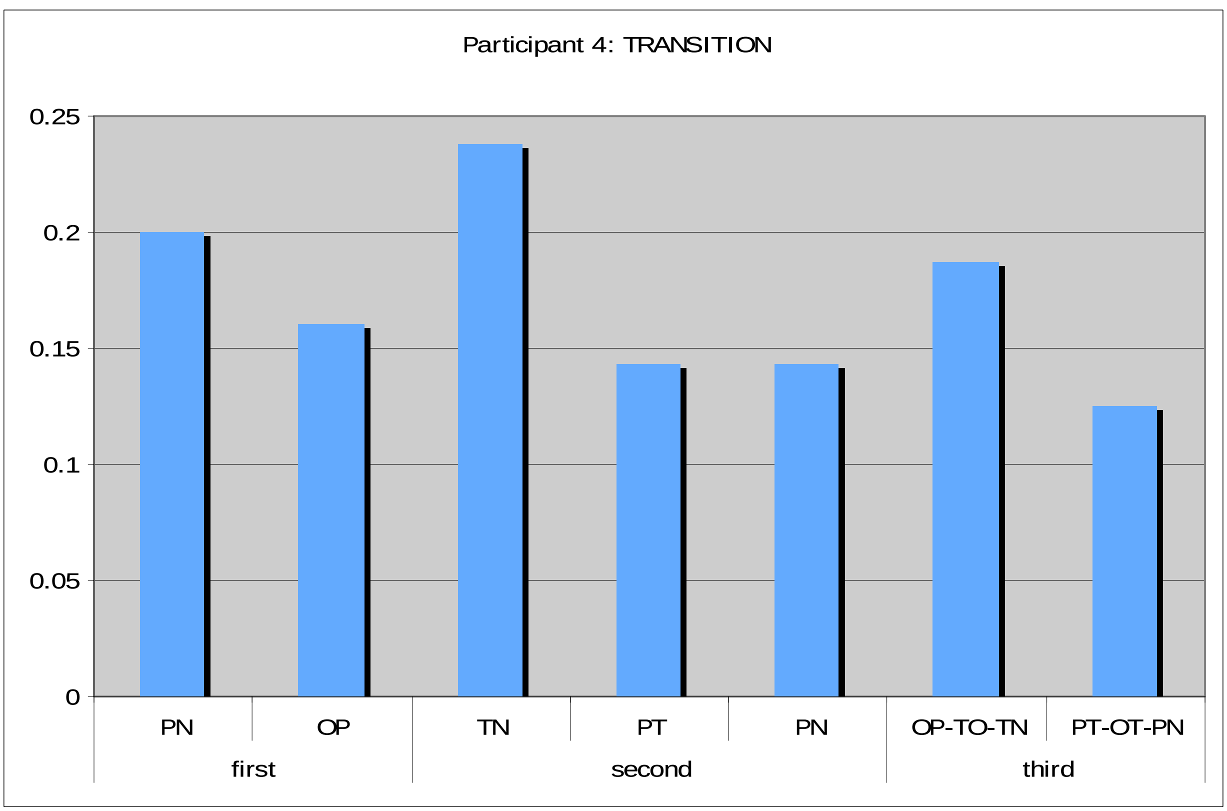

Participant D: TRANSITION
0.3
0.25
0.2
0.15
0.1
0.05
0
KN
OK
KO
OK-OT-TO
KO
OT
TK-TN
TO
OT
first
second
third
fourth

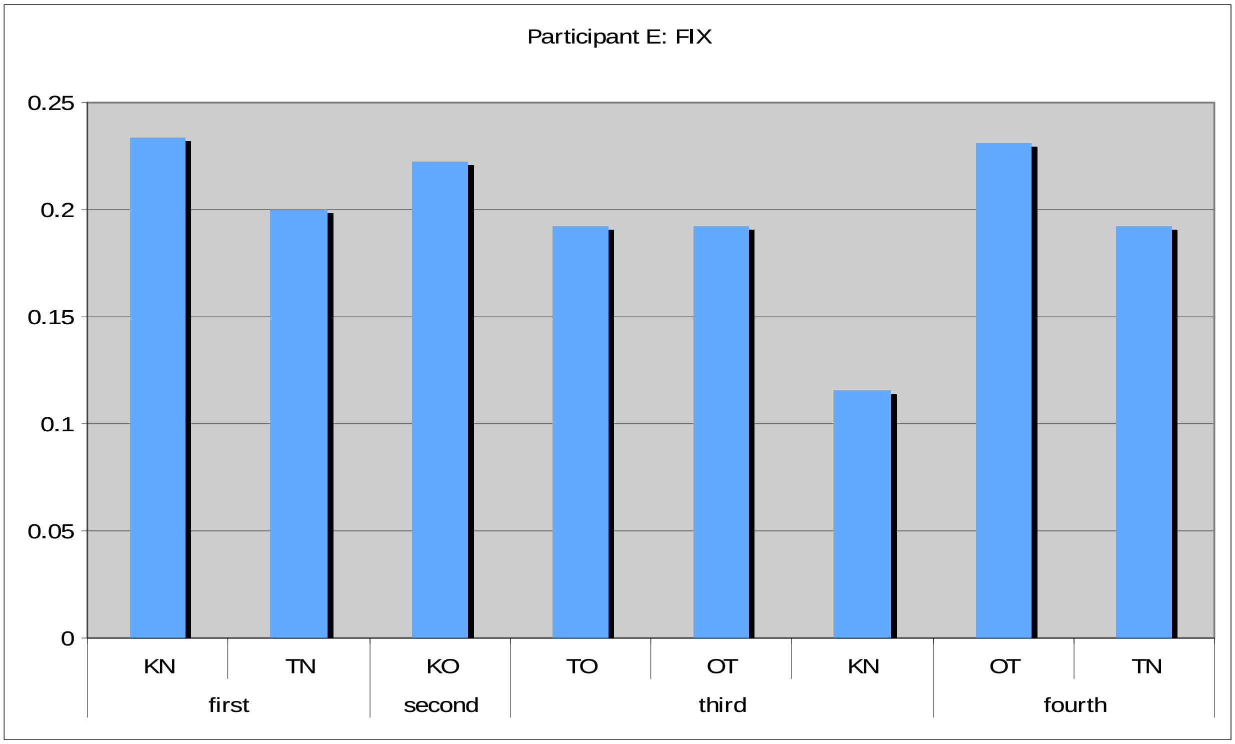

Participant 4: FIX
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
TP
OP
PT
TP
TN
TP
first
second
third

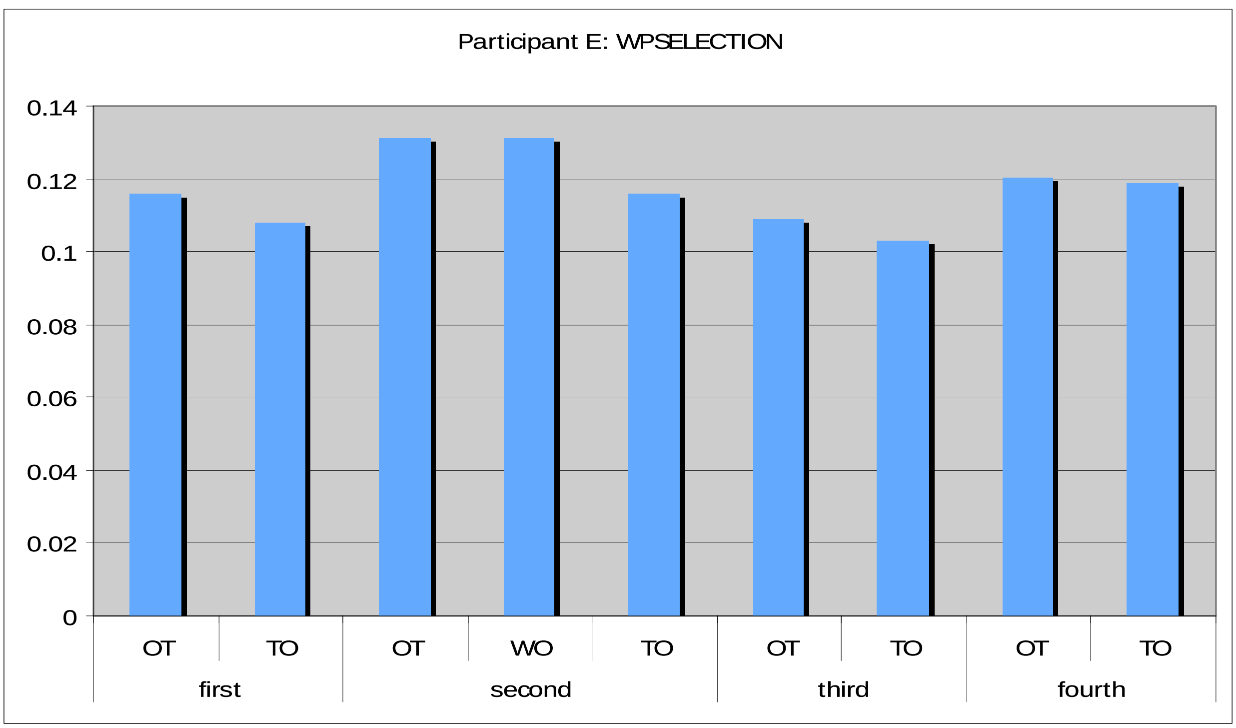

Participant 4: WPSELECTION
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
WP
TP
PT
WP
TP
first
second
third

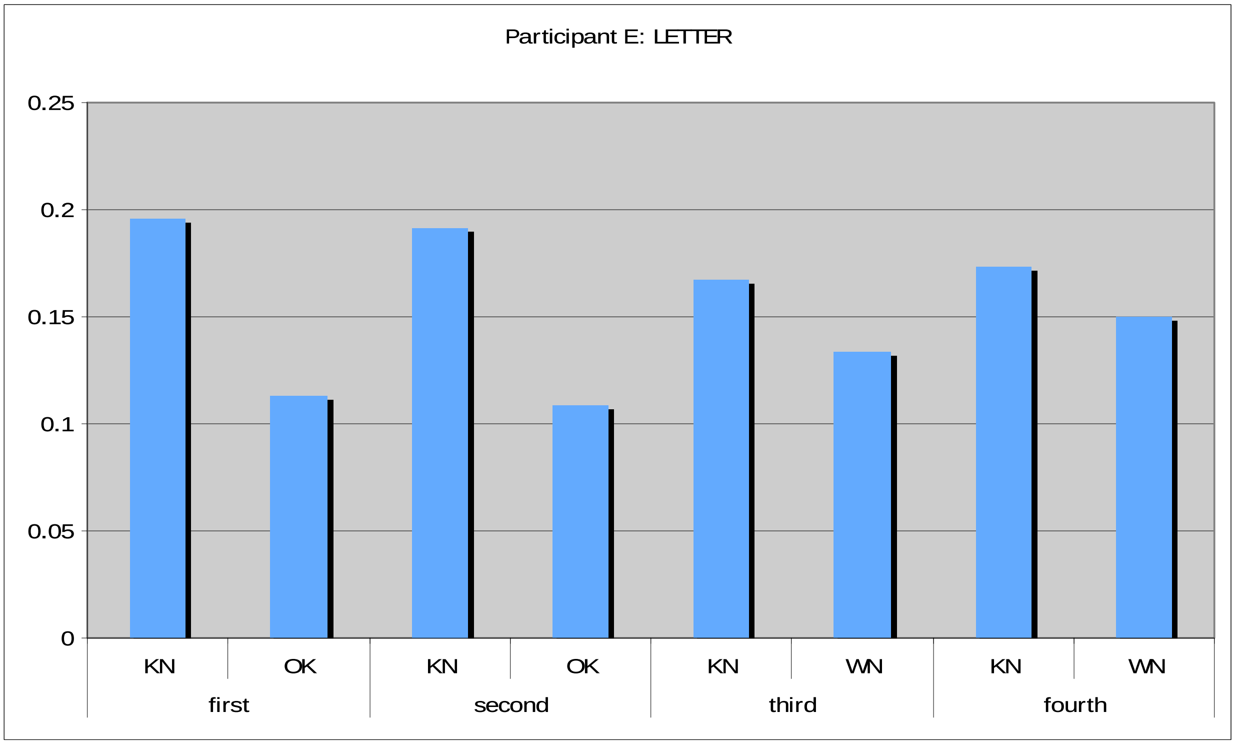

Participant 4: LETTER
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
PT
TN
TN
WP
TP
TN
first
second
third

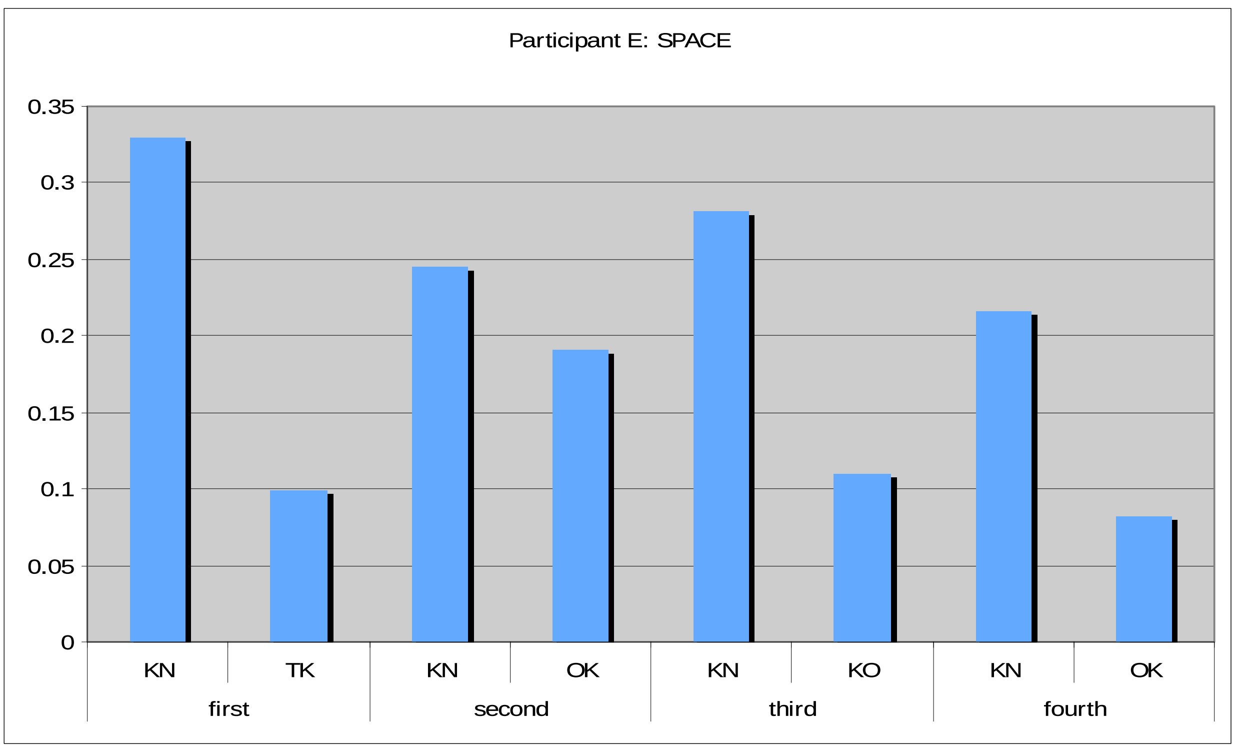

Participant 4: SPACE
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
PT
TP
WP
TN
TP
PO
TN
first
second
third

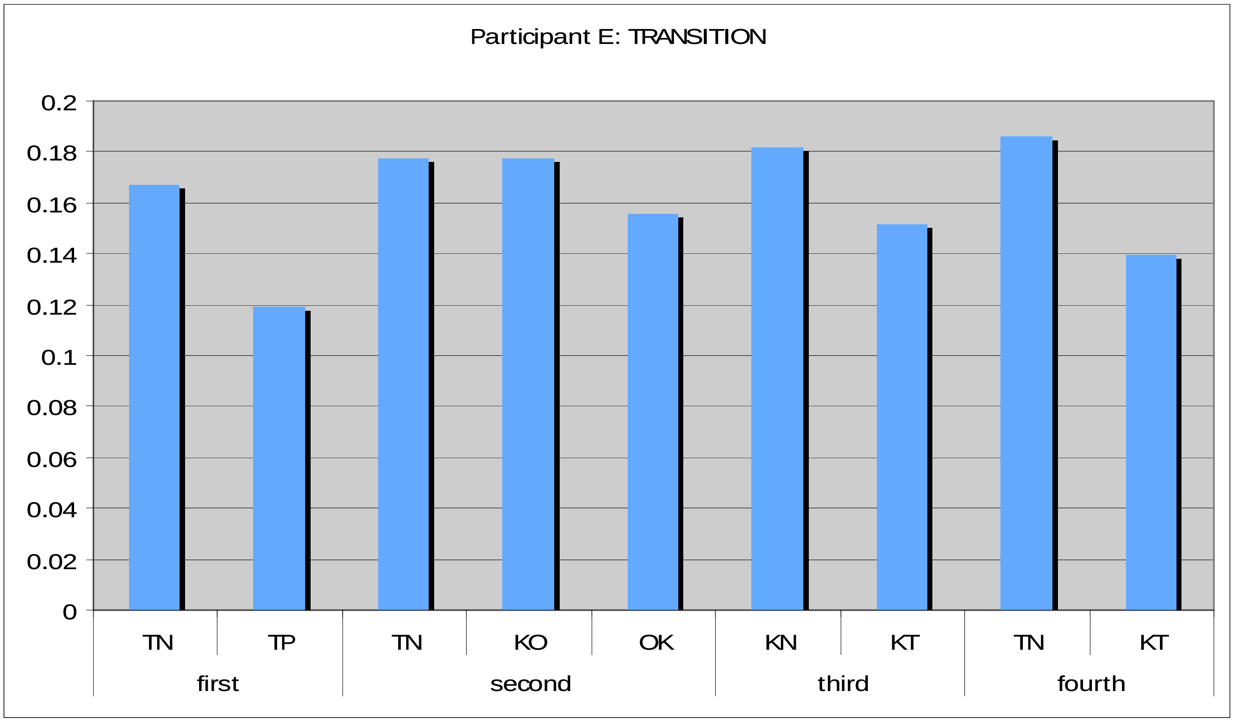

Participant 4: TRANSITION
0.25
0.2
0.15
0.1
0.05
0
PN
OP
TN
PT
PN
OP-TO-TN
PT-OT-PN
first
second
third

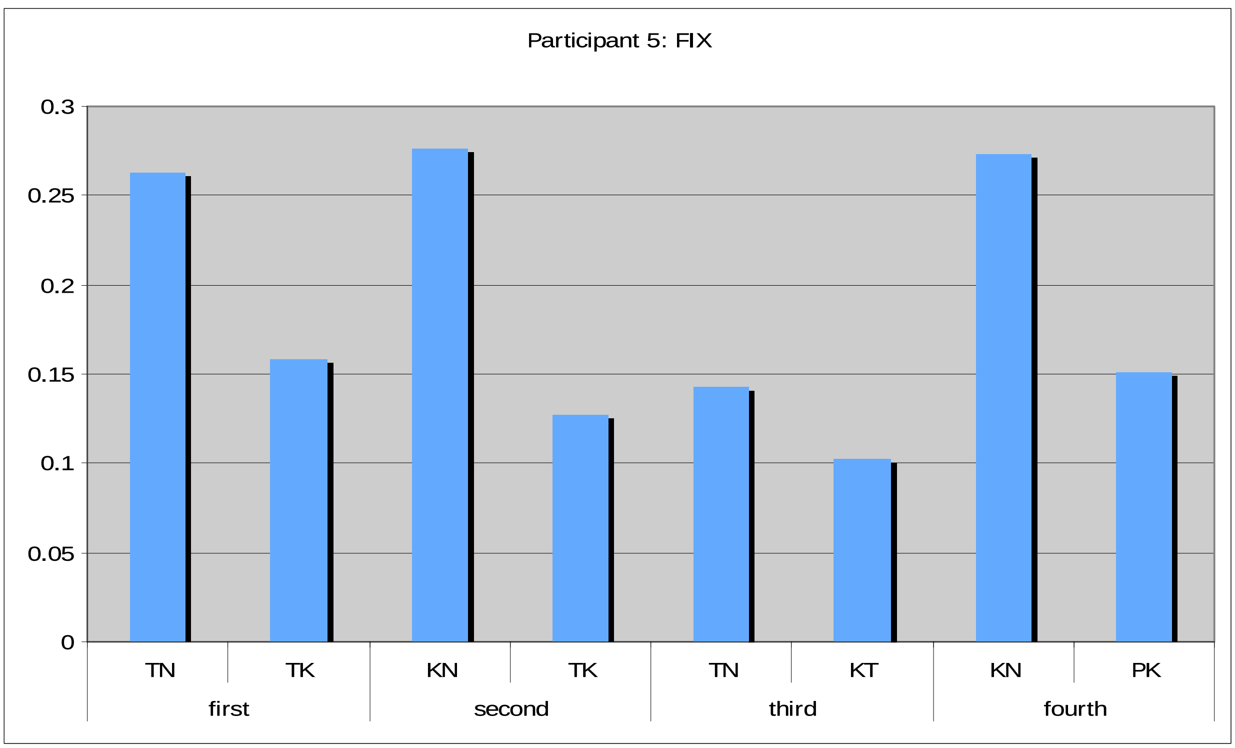

Participant E: FIX
0.25
0.2
0.15
0.1
0.05
0
KN
TN
KO
TO
OT
KN
OT
TN
first
second
third
fourth

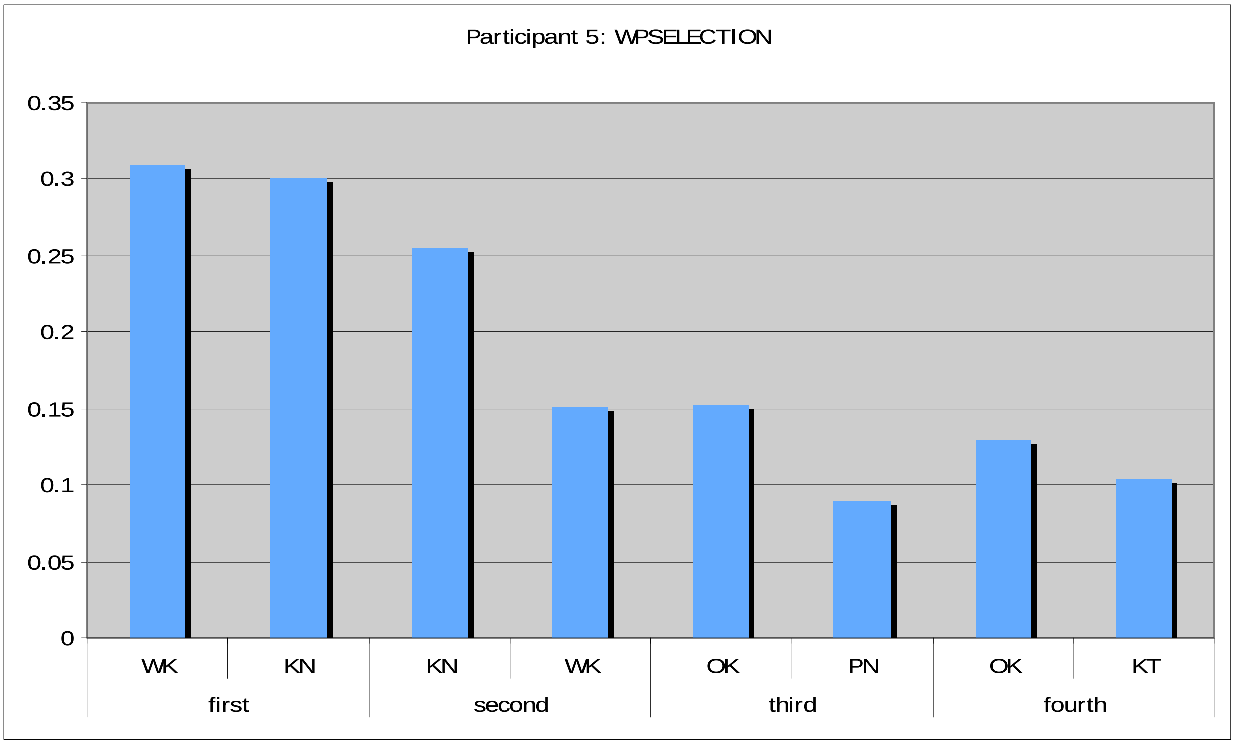

Participant E: WPSELECTION
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
OT
TO
OT
WO
TO
OT
TO
OT
TO
first
second
third
fourth

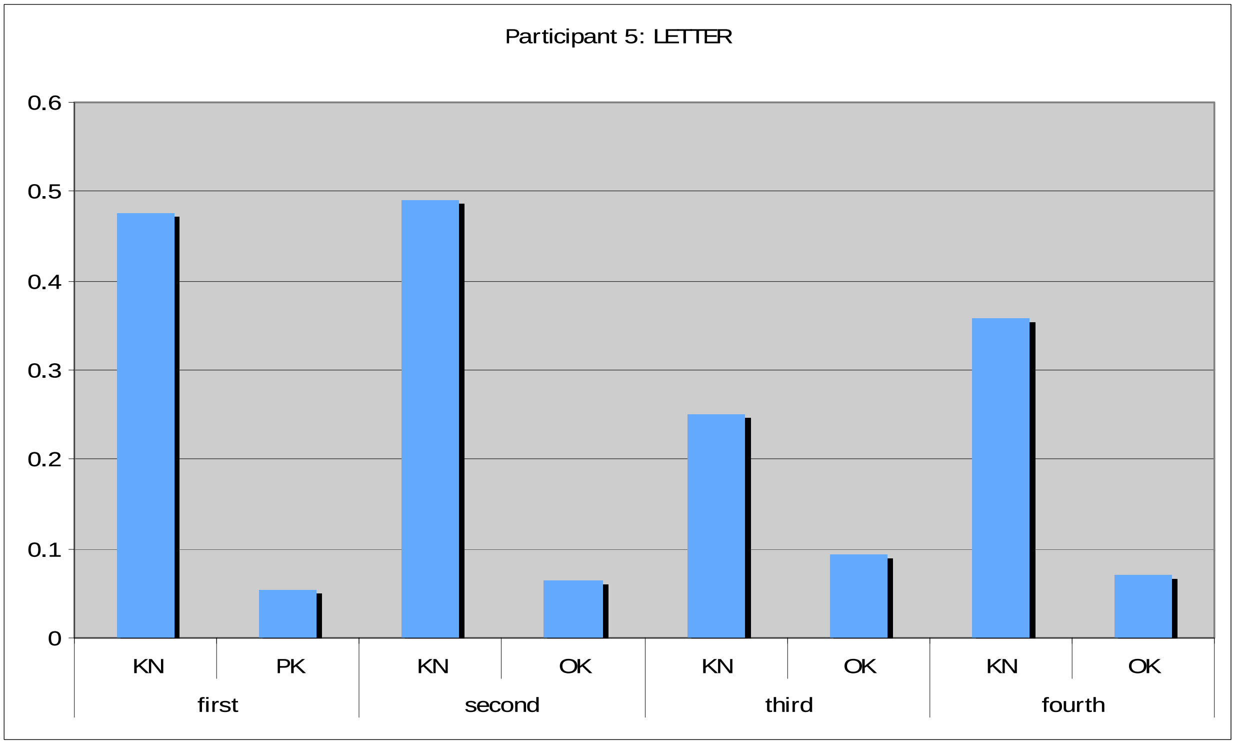

Participant E: LETTER
0.25
0.2
0.15
0.1
0.05
0
KN
OK
KN
OK
KN
WN
KN
WN
first
second
third
fourth

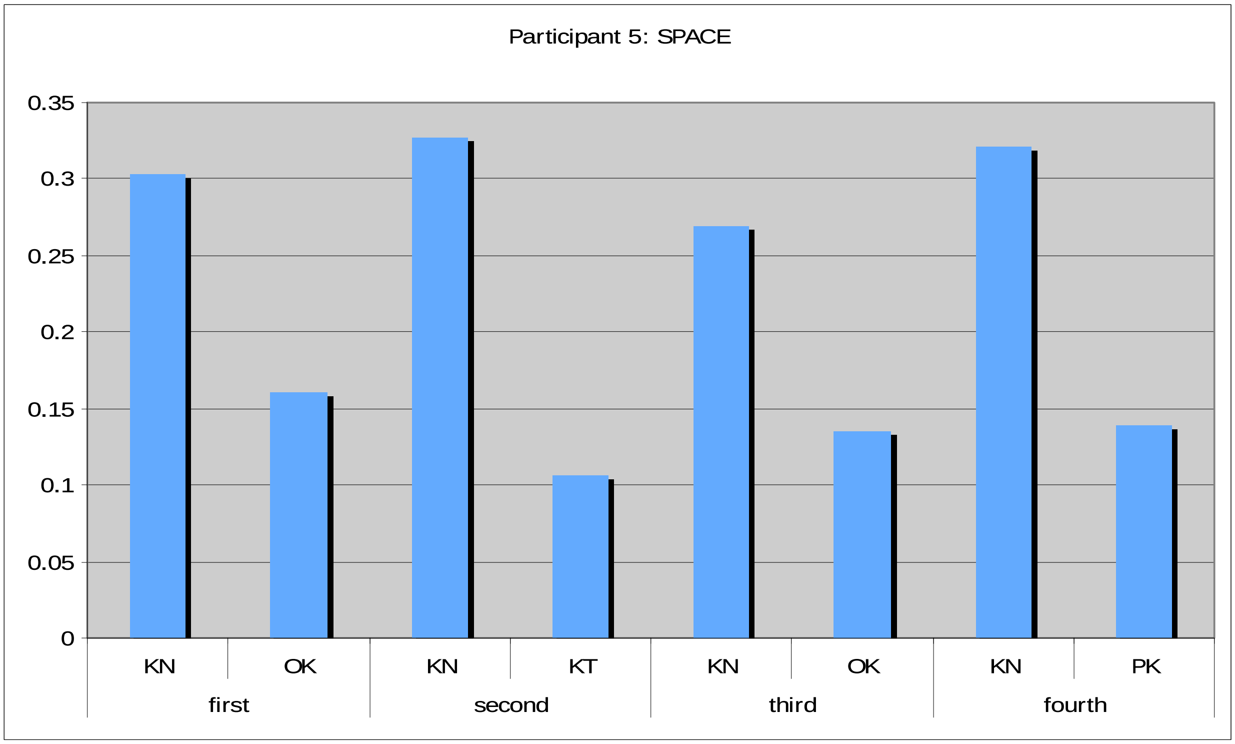

Participant E: SPACE
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
KN
TK
KN
OK
KN
KO
KN
OK
first
second
third
fourth

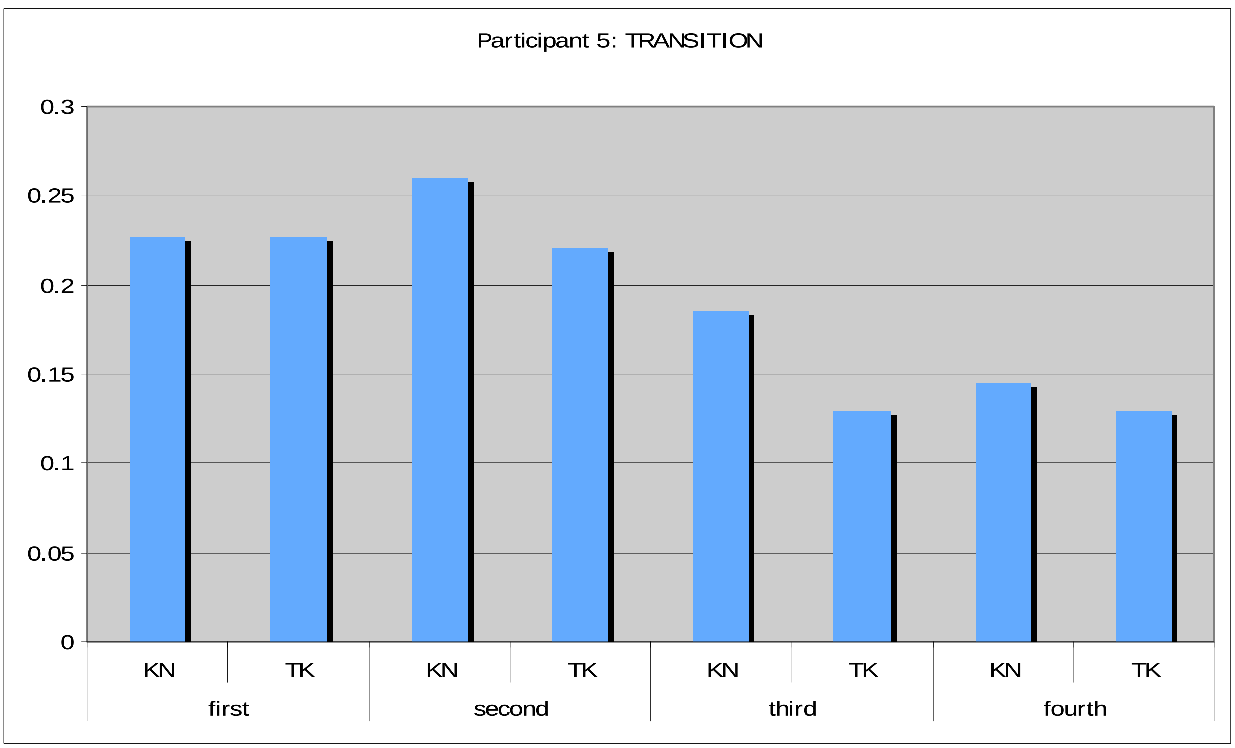

Participant E: TRANSITION
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
TN
TP
TN
KO
OK
KN
KT
TN
KT
first
second
third
fourth

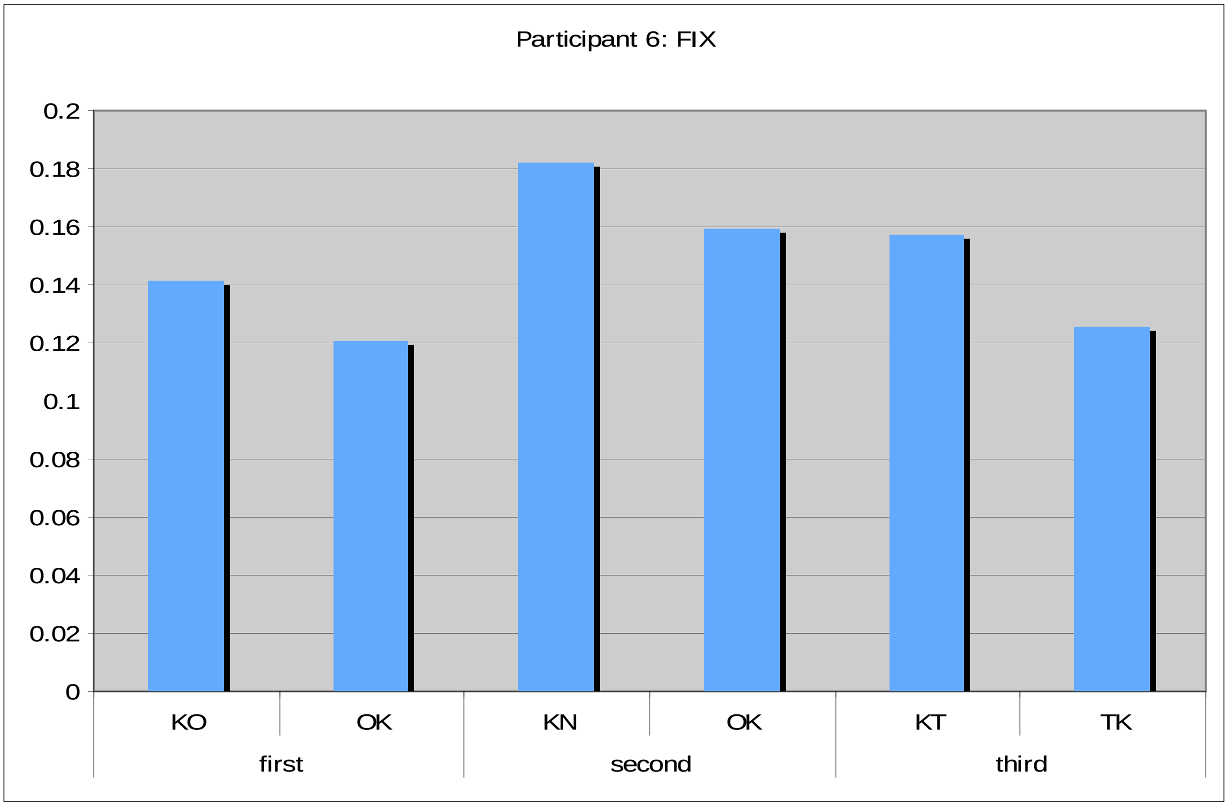

Participant 5: FIX
0.3
0.25
0.2
0.15
0.1
0.05
0
TN
TK
KN
TK
TN
KT
KN
PK
first
second
third
fourth

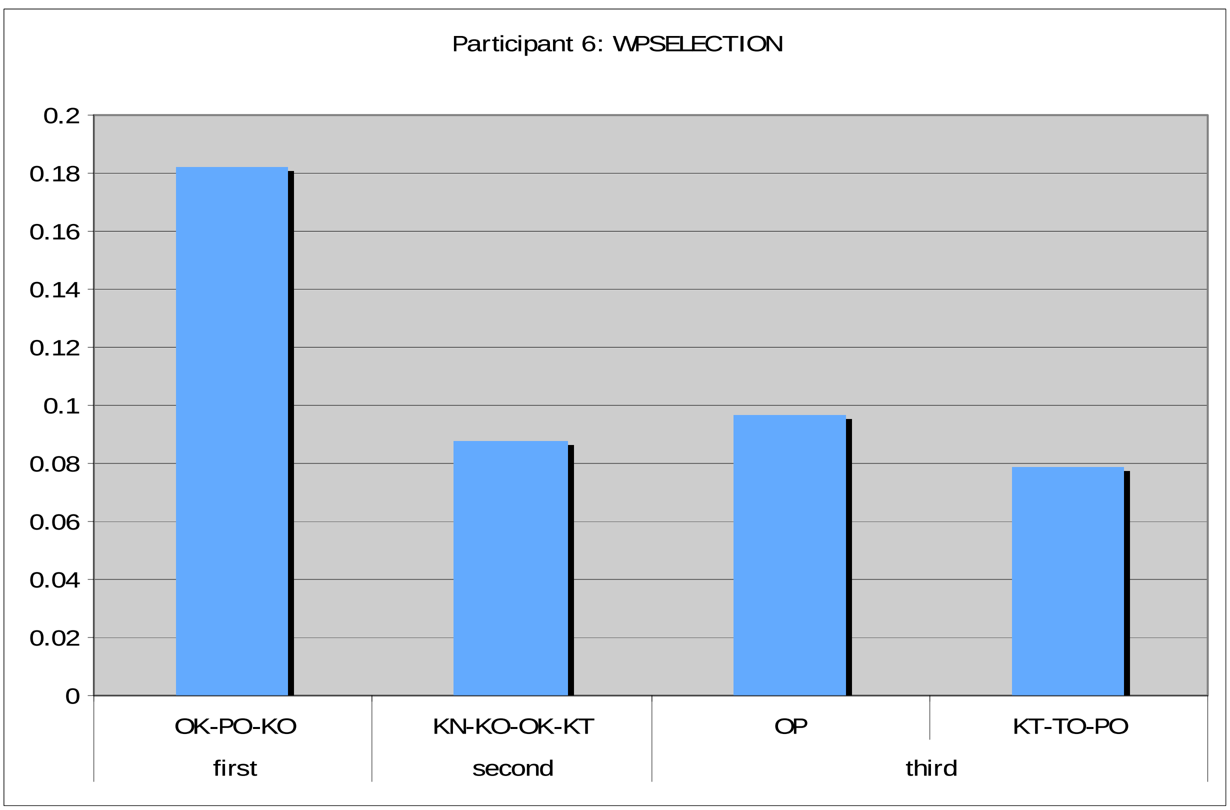

Participant 5: WPSELECTION
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
WK
KN
KN
WK
OK
PN
OK
KT
first
second
third
fourth

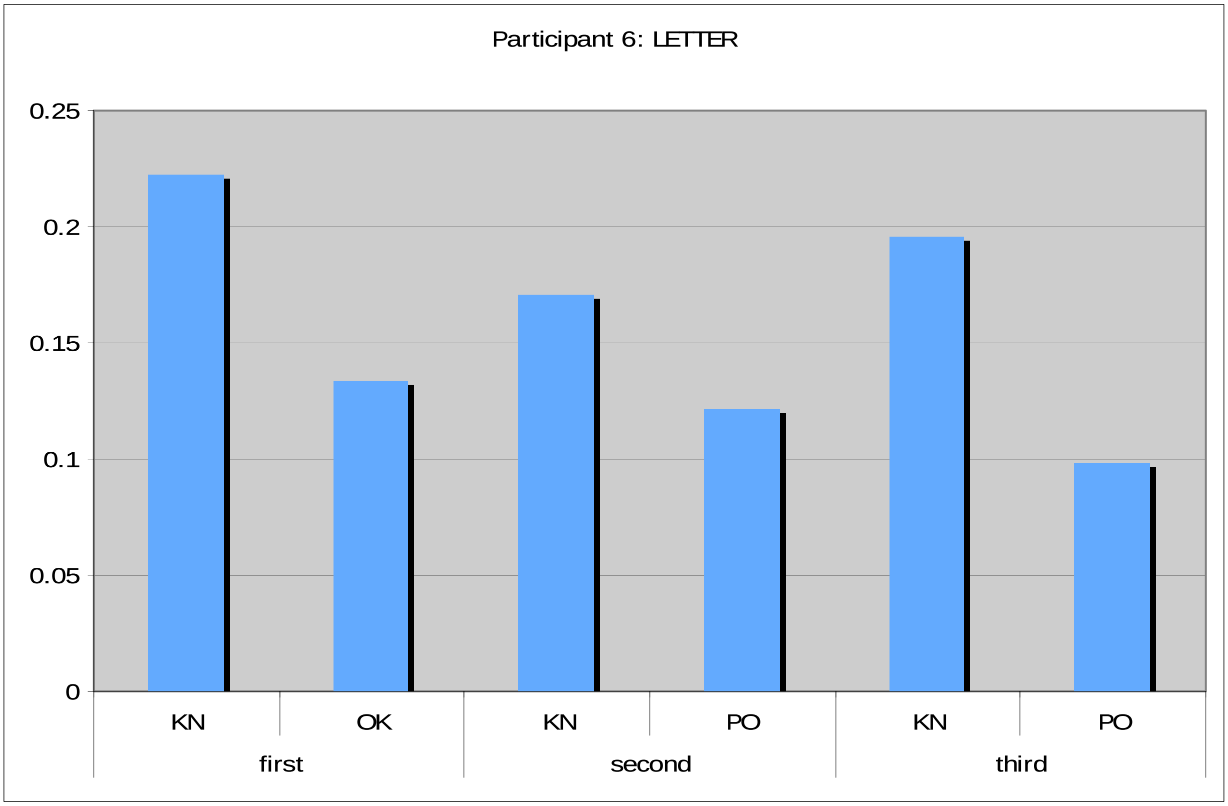

Participant 5: LETTER
0.6
0.5
0.4
0.3
0.2
0.1
0
KN
PK
KN
OK
KN
OK
KN
OK
first
second
third
fourth

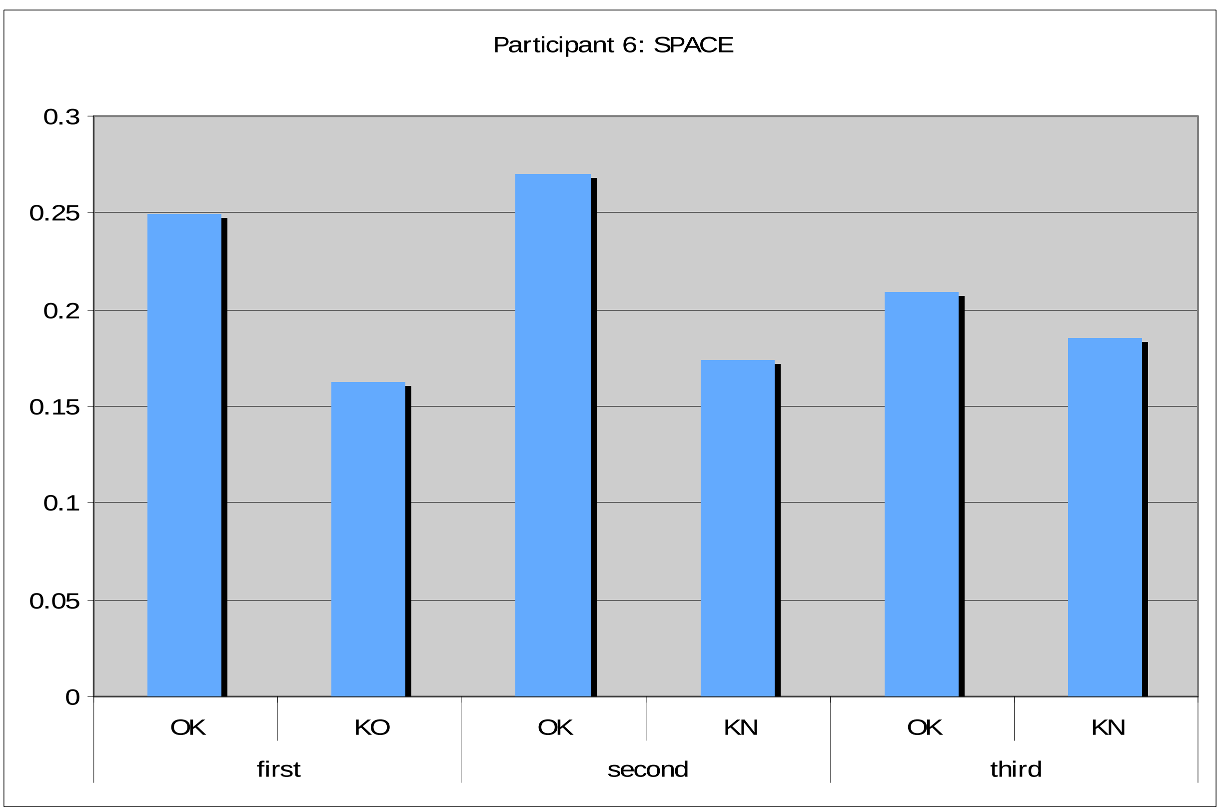

Participant 5: SPACE
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
KN
OK
KN
KT
KN
OK
KN
PK
first
second
third
fourth

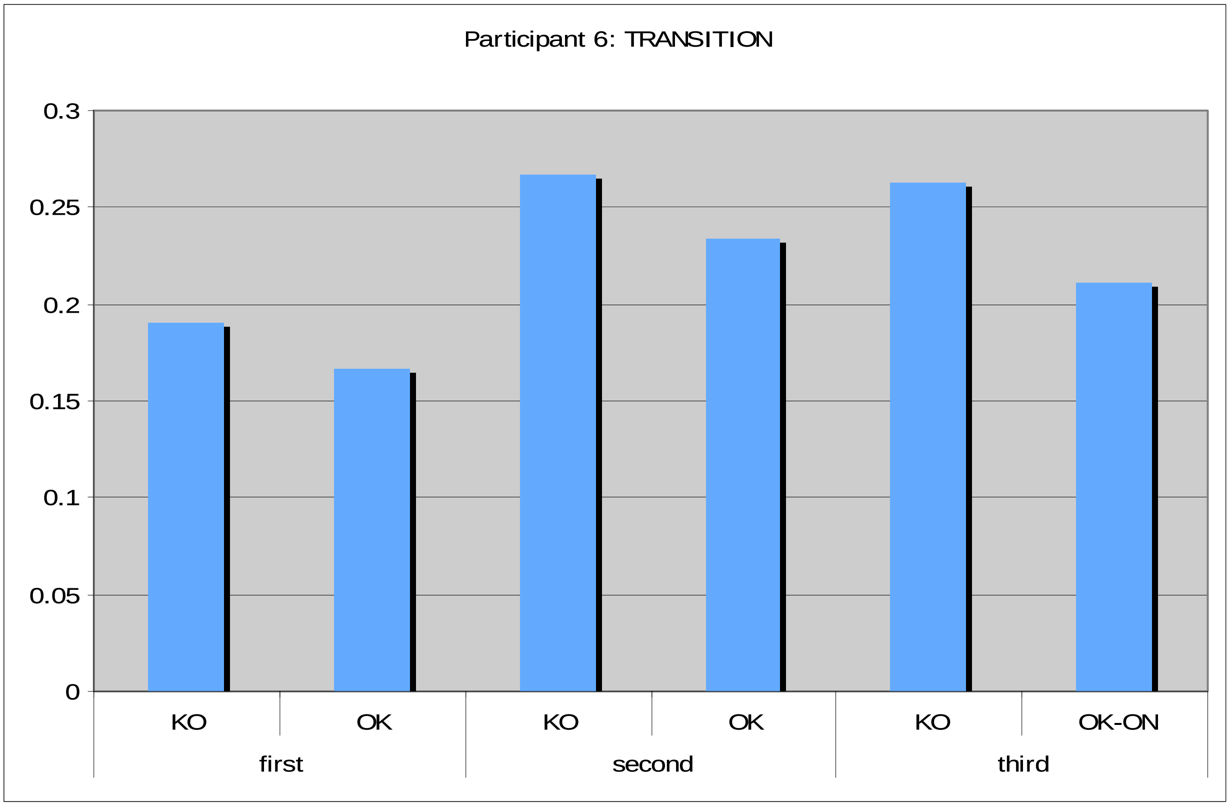

Participant 5: TRANSITION
0.3
0.25
0.2
0.15
0.1
0.05
0
KN
TK
KN
TK
KN
TK
KN
TK
first
second
third
fourth


Participant 6: FIX
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
KO
OK
KN
OK
KT
TK
first
second
third

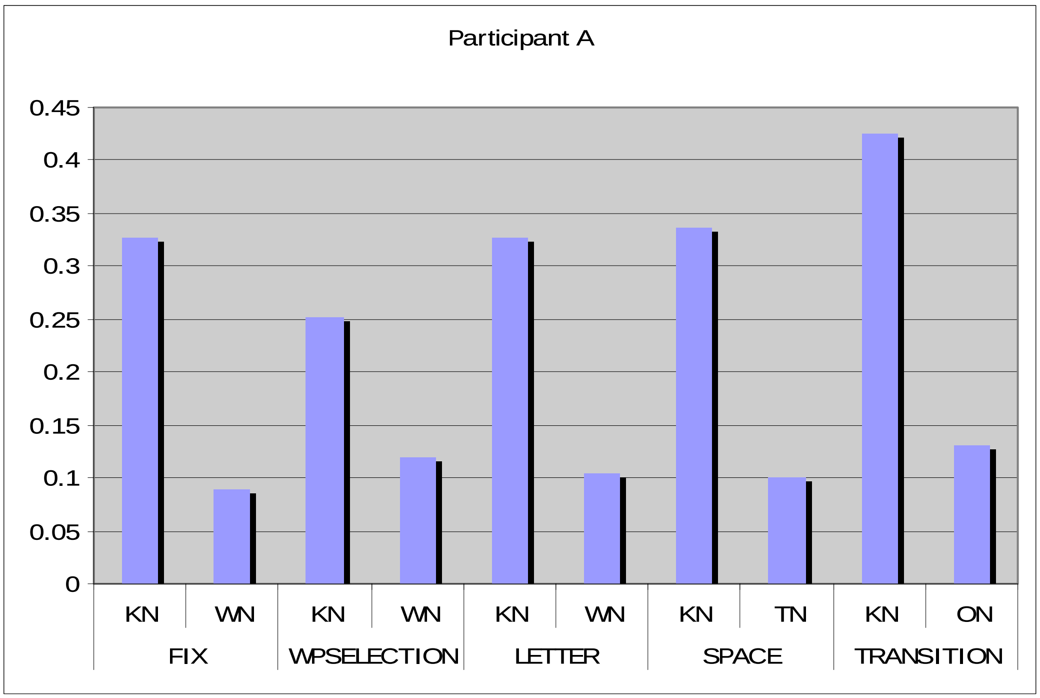

Participant 6: WPSELECTION
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
OK-PO-KO
KN-KO-OK-KT
OP
KT-TO-PO
first
second
third

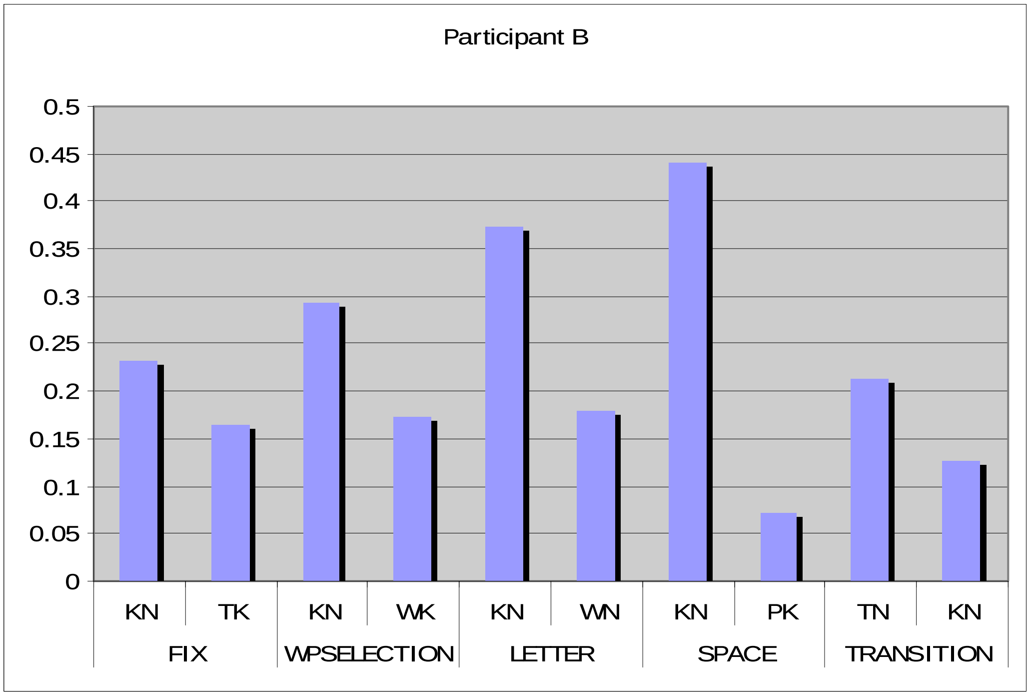

Participant 6: LETTER
0.25
0.2
0.15
0.1
0.05
0
KN
OK
KN
PO
KN
PO
first
second
third

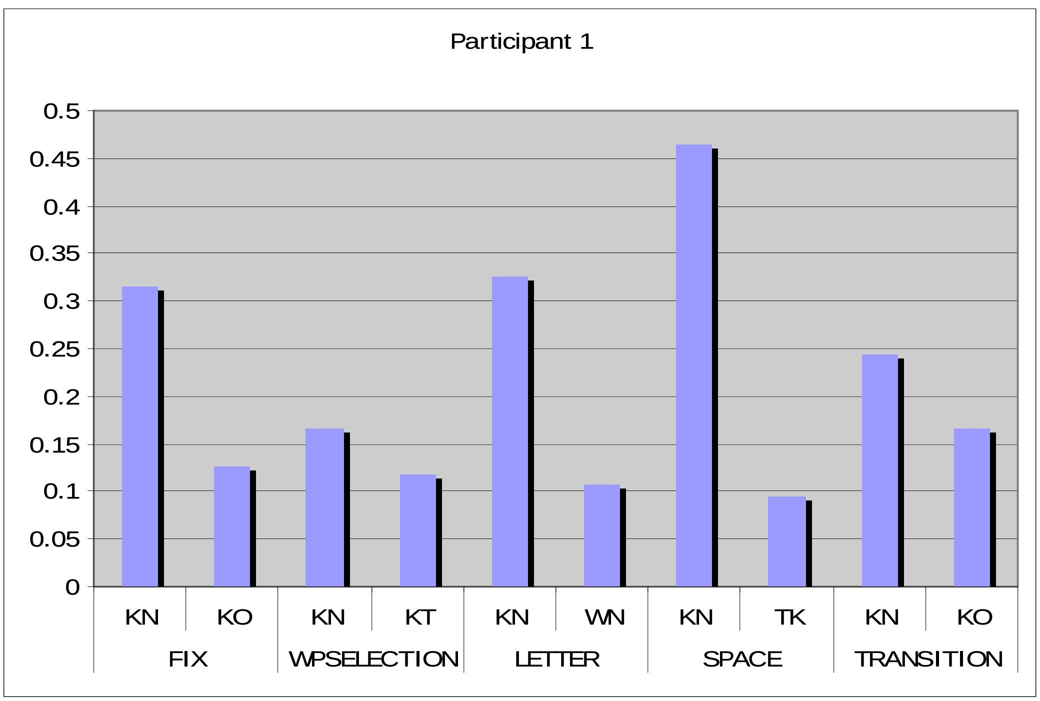

Participant 6: SPACE
0.3
0.25
0.2
0.15
0.1
0.05
0
OK
KO
OK
KN
OK
KN
first
second
third

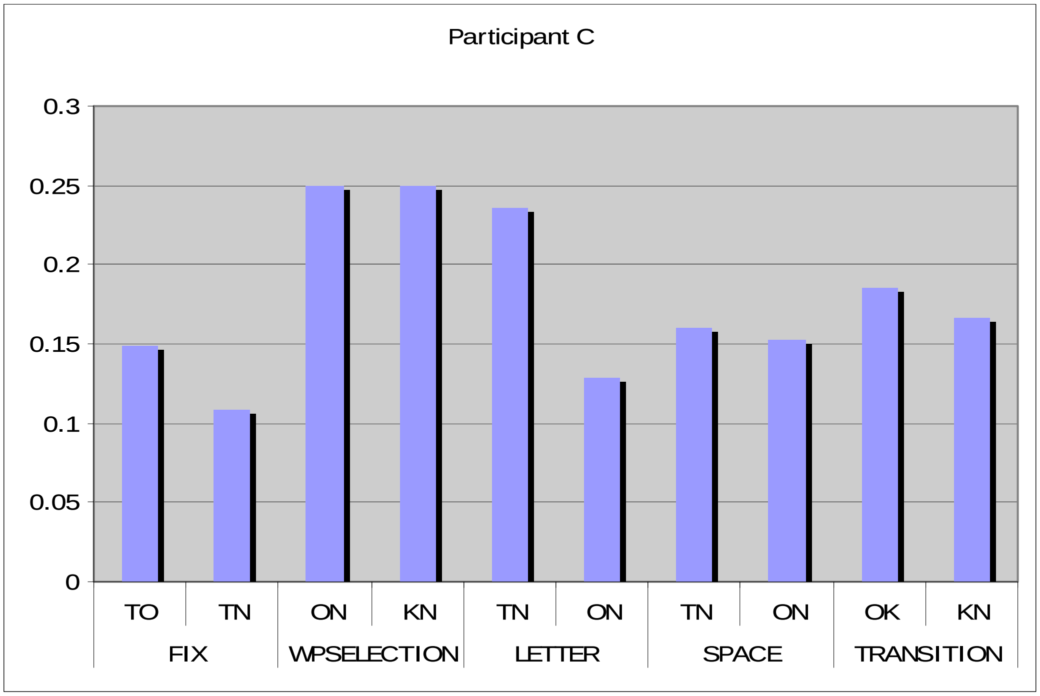

Participant 6: TRANSITION
0.3
0.25
0.2
0.15
0.1
0.05
0
KO
OK
KO
OK
KO
OK-ON
first
second
third

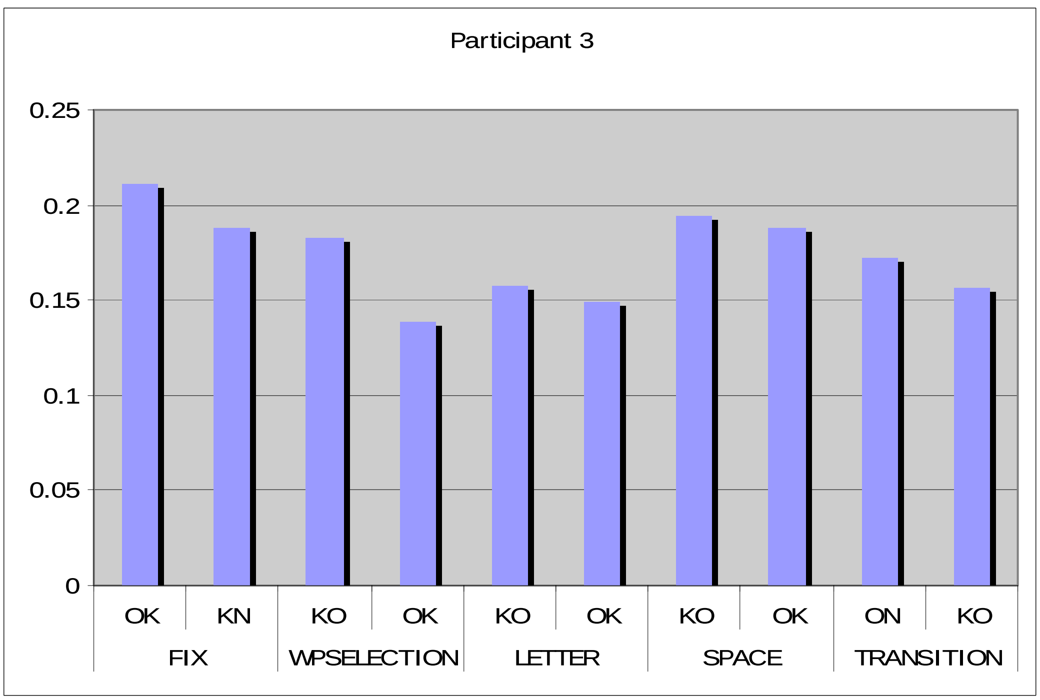
APPENDIX P: WITHIN SUBJECT CONSISTENCY BARCHARTS – ACROSS KEYSTROKE TYPE

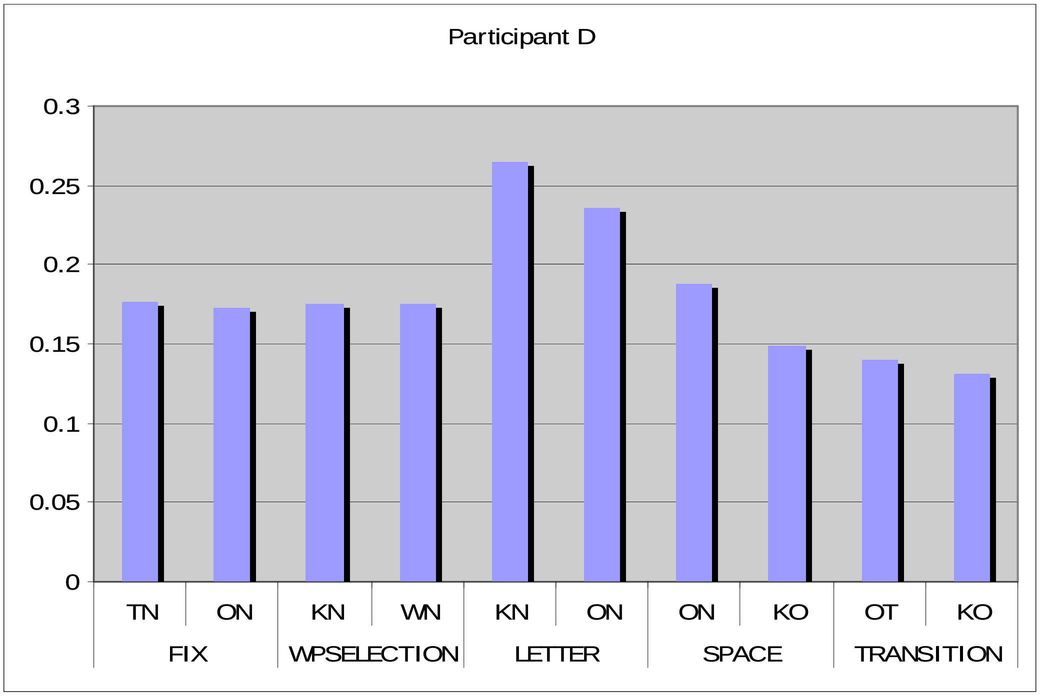


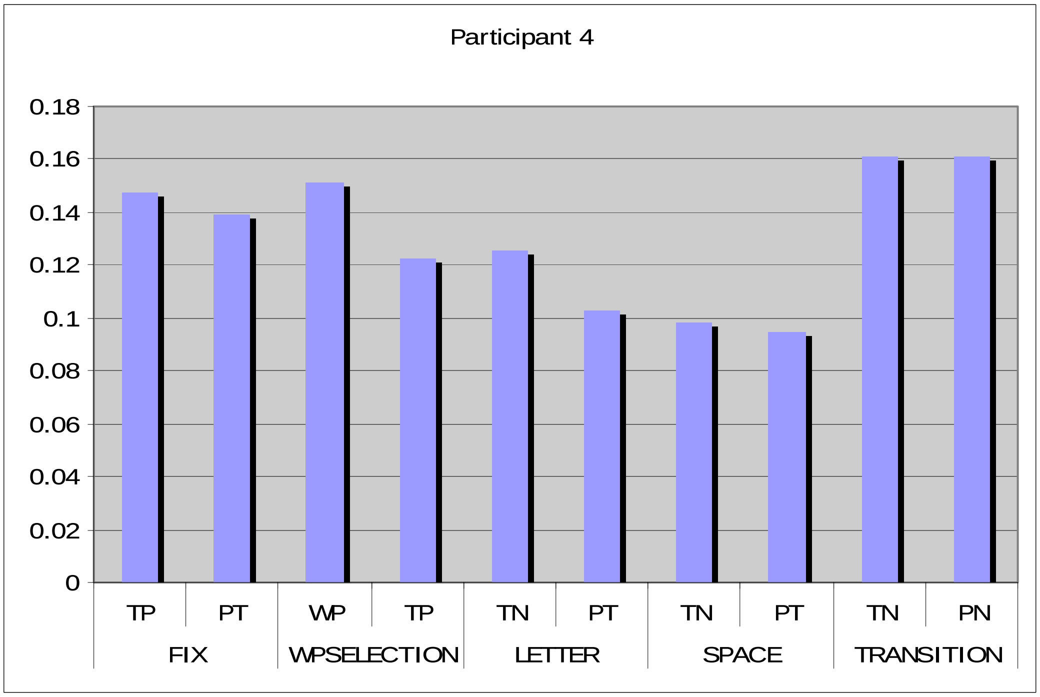

Participant B
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
KN
TK
KN
WK
KN
WN
KN
PK
TN
KN
FIX
WPSELECTION
LETTER
SPACE
TRANSITION

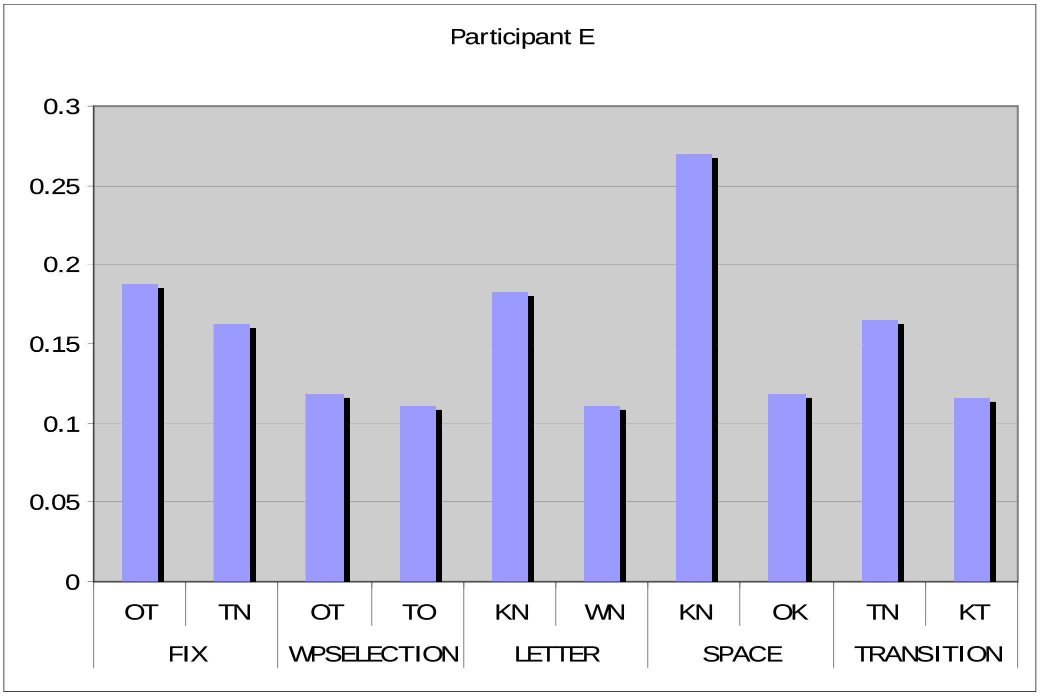

Participant 1
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
KN
KO
KN
KT
KN
WN
KN
TK
KN
KO
FIX
WPSELECTION
LETTER
SPACE
TRANSITION

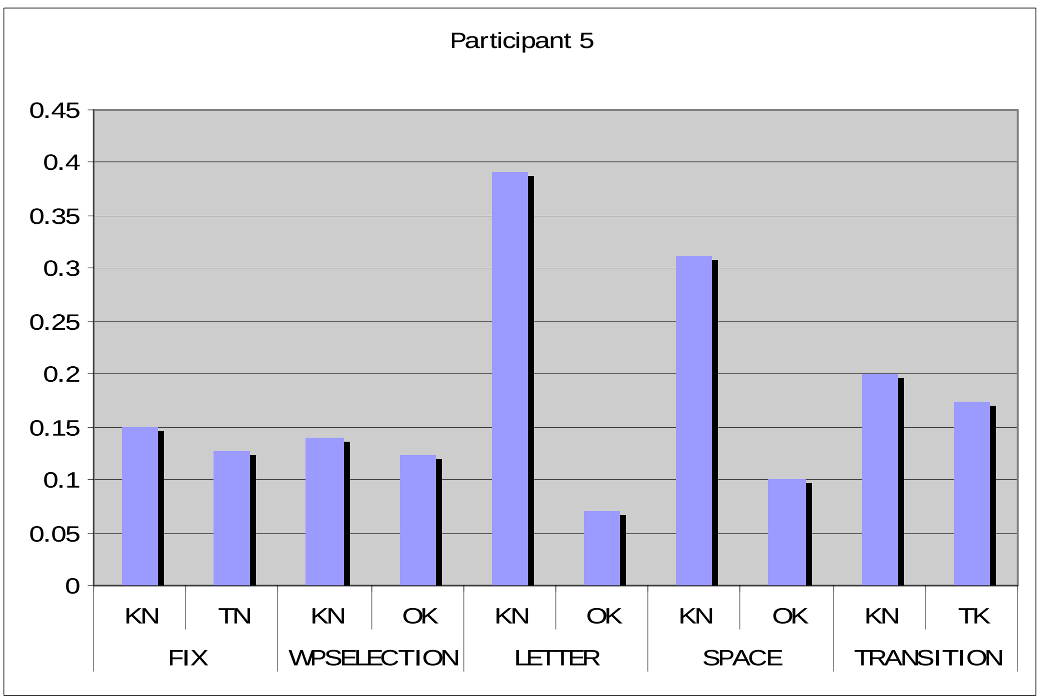

Participant C
0.3
0.25
0.2
0.15
0.1
0.05
0
TO
TN
ON
KN
TN
ON
TN
ON
OK
KN
FIX
WPSELECTION
LETTER
SPACE
TRANSITION

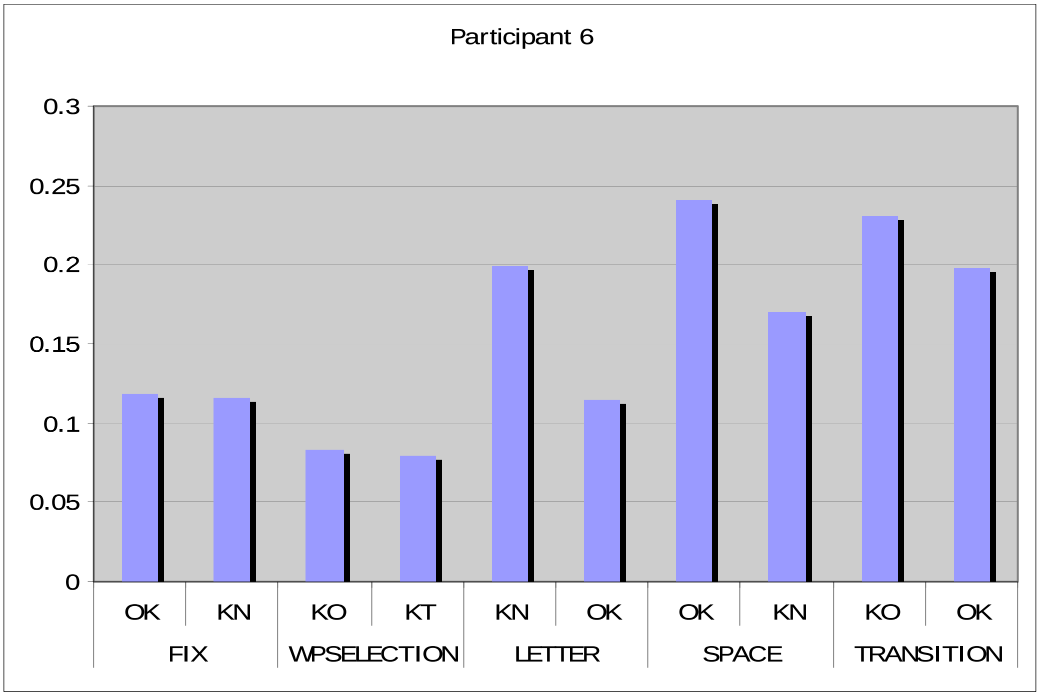

Participant 3
0.25
0.2
0.15
0.1
0.05
0
OK
KN
KO
OK
KO
OK
KO
OK
ON
KO
FIX
WPSELECTION
LETTER
SPACE
TRANSITION


Participant D
0.3
0.25
0.2
0.15
0.1
0.05
0
TN
ON
KN
WN
KN
ON
ON
KO
OT
KO
FIX
WPSELECTION
LETTER
SPACE
TRANSITION


Participant 4
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
TP
PT
WP
TP
TN
PT
TN
PT
TN
PN
FIX
WPSELECTION
LETTER
SPACE
TRANSITION


Participant E
0.3
0.25
0.2
0.15
0.1
0.05
0
OT
TN
OT
TO
KN
WN
KN
OK
TN
KT
FIX
WPSELECTION
LETTER
SPACE
TRANSITION


Participant 5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
KN
TN
KN
OK
KN
OK
KN
OK
KN
TK
FIX
WPSELECTION
LETTER
SPACE
TRANSITION


Participant 6
0.3
0.25
0.2
0.15
0.1
0.05
0
OK
KN
KO
KT
KN
OK
OK
KN
KO
OK
FIX
WPSELECTION
LETTER
SPACE
TRANSITION

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