Deconstructing Skilled Typing Performance:
An Investigation of Key Selection and Keystroke Execution Processes

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CHAPTER I

INTRODUCTION

For most of us, typing is a ubiquitous and effortless task. Typically, we are only aware of the words we intend to type because the details of our finger movements are controlled implicitly (Liu, Crump, & Logan, 2010; Logan, & Crump, 2009; Snyder, Ashitaka, Shimada; Ulrich, & Logan, 2013). Nevertheless, the ease with which typing is undertaken is especially impressive when considering the complexity of the task: Words are spelled with specific, usually unique, letter sequences and each letter has a corresponding key on the QWERTY keyboard, which are relatively small and are positioned in close proximity to each other. Therefore, to type the appropriate sequence, one of eight possible fingers must produce a keystroke to the correct location of one of 26 possible lettered keys quickly, accurately, and in the appropriate order. Despite this complexity, extensive practice interacting with QWERTY keyboards has enabled our cognitive systems to develop a processing structure that is capable of managing the task's details implicitly (i.e. without conscious effort). This study investigates the architecture of that processing structure.

Skilled typing is generally believed to be controlled hierarchically (Fendrick, 1937; Gentner, Grudin, & Conway, 1980; Larochelle, 1983; 1984; Miller, Galanter, & Pribram, 1960; Shaffer, 1975; 1976; Shaffer, & Hardwick, 1968; Soetching, & Flanders, 1992; Sternberg, Monsell, Knoll, & Wright, 1978; Terzuolo, & Viviani, 1980; West, & Sabban, 1982). Accordingly, Logan and Crump (2009; 2011) recently theorized that skilled typing is controlled by two, nested processing loops (Logan, & Crump, 2009; 2011): An explicit outer processing loop that produces a sequence of intended words and sends one word at a time to an implicit inner processing loop, which produces the corresponding sequence of keystrokes. Logan and colleagues have also suggested that the transformation of an intended word to the appropriate keystroke sequence relies on associations between words and letters, letters and keys, and between keys and finger movements (Yamaguchi, et al., 2013; Yamaguchi, & Logan 2014a; 2014b; Yamaguchi, Logan, & Li, 2013). However, the structure of the processes responsible for that transformation has not been investigated directly.

Accurate typing requires pressing specific keys in specific orders. Therefore, it intuitively seems as though the inner loop must have at least two, conceptually distinct, responsibilities: Key selection, which refers to the choice of one target key from the pool of 26 possible lettered-key options, and keystroke execution, which refers to the production of a finger movement to a target key. Indeed, skilled typing studies have traditionally attributed some aspects of performance to a key selection process and other aspects to a keystroke execution process (Gentner, Larochelle & Grudin, 1988; Grudin, 1983; F. A. Logan, 1999; MacNeilage, 1964; Salthouse, 1986; Shaffer, & Hardwick, 1969; Wells, 1916; Yamaguchi, et al., 2013).

While this traditional division of labor may be intuitive, it is important to note that it makes two implicit assumptions about the structure of the processes that are responsible for transforming a to-be-typed word into a keystroke sequence. One assumption is that key selection and keystroke execution are serial. This assumption stems from the notion that the choice of what to do should logically precede the doing of an intended action. The other assumption is that key selection and keystroke execution are independent. Attributing typing errors to either the choice of the wrong key or to an inaccurate keystroke movement as classic typing studies do (Gentner, et al., 1988; Grudin, 1983; F. A. Logan, 1999; MacNeilage, 1964; Salthouse, 1986; Shaffer, & Hardwick, 1969; Wells, 1916), requires that the difficulty or time necessary to select a key has no influence on the difficulty or the time necessary to execute a keystroke and vice versa.

Processing Structures: An Introduction

What does it mean to say that the structure of key selection and keystroke execution processes are independent and serial? To answer this, it is necessary to take a step back and discuss processing structures: Fundamental to cognitive psychology is the notion that information is transformed through a series of mental operations, or processes, from the presentation of a stimulus, or inception of a goal, to the execution of a response. This notion dates back at least as far as Donders (1868), who posited that processing occurs within functionally specialized steps, or stages, that receive a specific form of information (i.e., input) and produce a different form of information (i.e., output), which is then transmitted to the next stage until, eventually, a response is produced. The term *processing structure* refers to the characteristics and arrangement of the processes that are necessary for a given task.

The most basic processing structure is generally understood to be one in which independent processes are ordered serially and information transmission between stages is discrete. Here, independence refers to stochastic independence (i.e., $P(A \cap B) = P(A) \times P(B)$): The conditional probability of Process A finishing at time t_1 given the probability that Process B finishes at time t_2 equals the unconditional probability of Process A finishing at time t_1 (Townsend, & Thomas, 1994). Processes are serial when the output of Process A is the input of Process B (Logan, 2002). Information transmission is discrete when a single unit of information is passed between processes at a single moment in time (Miller, 1988).

In basic serial processing structures, stages receive information through a single input channel. However, it is also possible that stages could receive information through multiple channels. In such cases, the information received through separate channels may be processed independently in parallel. In parallel processing structures, processing times for the various channels are likely to vary, so the time at which information is transmitted to the next stage is determined by one of two stopping rules (Townsend, & Thomas, 1994): A self-terminating stopping rule allows information to be transmitted to the next stage as soon as the processing in one channel finishes. An exhaustive stopping rule allows information to be transmitted to the next stage when the processing in all channels finish (Townsend, & Nozawa, 1995). Co-active processing structures in which information that is received through separate channels feed into a single channel where it is processed jointly are also possible.

The Investigation of Processing Structures

Donders (1868) is generally accredited with being one of the first to pioneer the investigation of processing structures. He assumed a basic serial processing structure and suggested that the duration of Stage X could be measured by subtracting the reaction time (RT) for Task A from the reaction time for Task B when the only difference between the tasks is that Task B requires Stage X and Task A does not. However, a limitation of Donders' so-called subtraction method is that the difference in RTs between the tasks may be due to Task B requiring more than one additional stage, relative to Task A, or no additional stages and instead simply requiring a longer duration of a stage that both tasks have in common.

A century later, Sternberg (1969), posited that it would be possible to investigate whether specific aspects of a task are processed within a common stage or by different stages by assessing the effects of experimental factors on RT. According to his additive factors methodology, when experimental factors selectively influence aspects of a task that are processed by stages that are independent and serial, their effects on RT will be additive. On the other hand, when experimental factors affect aspects of a task that are processed within a common stage, their effects on RT will be interactive, and most likely over-additive.

In the decades since Sternberg (1969) introduced his additive factors method, work, collectively known as Systems Factorial Technology (Fific, Nosofsky, & Townsend, 2008; Schweickert, & Townsend, 1989; Townsend, 1984; Townsend, & Ashby, 1983; Townsend, & Nozawa, 1995; Townsend, & Thomas, 1994), has demonstrated that the interpretation of factor effects is not always straightforward: Over-additive factor effects are not diagnostic of a particular processing structure because they are produced when factors affect a common process within a serial structure or when factors affect a parallel self-terminating or a co-active structure. Also, when factors affect a common stage, they do not always produce over-additive effects. In fact, when factors affect a parallel exhaustive structure, they produce under-additive effects. Another, and perhaps most problematic, complication revealed by the work on systems factorial technology is that while factors that affect serial, independent processes do indeed produce additive effects, it is also possible for factors to affect a common process or stage within a serial structure in such a way that just so happens to produce additive effects on RT. This possibility will be referred to here as a *misleading additive effect*.

Misleading additive effects are potentially fatal for the additive factors methodology (AFM). AFM is based on the notion that additive effects are indicative of factors affecting processes that are independent and serial while interactive effects are indicative of factors affecting a common process. Therefore, if additive effects could be produced in either case the method would be rendered useless.

Misleading additive effects are possible because the additive factors methodology and systems factorial technology assume that experimental factors affect process durations without specifying how they do so. As a result, there is no way to make a priori predictions about the way in which factor effects will combine. However, such ambiguities can be resolved with theory: Developing a model that specifies the underlying mechanisms that determine process durations and the means by which experimental factors could affect their durations allows for the formulation of specific predictions about the kinds of effects combinations of factors will have. Once derived, the predictions can then be applied to the choice of experimental factors so as to avoid evaluating the effects of factors that would produce misleading additive effects. Therefore, below, I introduce a two-step model of inner loop processing that will guide the current investigation.

The Two-Step Model of Inner Loop Processing

The proposed model assumes that the process of transcription typing begins with the visual analysis of presented text and ends with keystrokes. In between is a network of representational nodes that are linked via associations, which transmit activity among the nodes. The amount of activity transmitted depends on the extent to which antecedent nodes are active, the strength of the associations among the nodes, and the number of steps activity has traveled because activity is assumed to decay with each additional step

(Anderson, 1983; Collins, & Loftus, 1975; DeGroot, 1983; Dehaene, Changeux, Naccache, Sacker, & Sergent, 2006; Dell, 1986; McClelland, & Elman, 1986).

The representational network is comprised of four layers: Orthographic, semantic, pointer, and key. First, the result of the visual analysis sends activity to nodes in the orthographic layer in proportion to the extents to which individual orthographic representations match the presented text. Second, activity spreads down from active orthographic nodes to their corresponding semantic networks in the semantic layer. Each meaning of a word is assumed to be represented by separate nodes in the semantic layer, all of which are assumed to be automatically and simultaneously activated in proportion to the strengths of their associations (Hino, Lupker, & Pexman, 2002; Hino, Pexman, & Lupker, 2006; Jastremski, 1981; Klein, & Murphy, 2002; Pexman, Hino, & Lupker, 2004; Pexman, & Lupker, 1999; Rodd, 2004; Rubenstein, Garfield, & Milliken, 1970). Activity is also assumed to spread out laterally from the presented word's meaning or meanings to the nodes of related concepts within their semantic networks. Third, activity spreads down from the semantic layer to the pointer layer. Pointer representations code information about the identity and order of the keys necessary to type the word that corresponds to the semantic node from which activation was received. Fourth, activity spreads from the pointer layer to the key layer. Key representations code information about the location of a given key, the motor code for how fingers should be moved to hit the target location, or both.

Key representations must be selected before keystroke movements can be executed. Key selection is assumed to be a stochastic choice process in which activity accumulates to a threshold, such that a key is "selected" when a key representation's activity level reaches its threshold. Time to threshold depends on the distance between the starting point and threshold levels as well as drift rate. Starting points are assumed to be constant. As a result, the distance between starting point and threshold is determined by threshold levels. Drift rates (i.e., the speeds with which accumulators accrue activity) are assumed to be constant within a trial and to vary between trials. Drift rates are estimated by Luce's choice ratio (1959): The weight of the evidence for the correct option divided by the summed weights of the evidence for all possible options. Luce's choice ratio is a means of estimating the probability of choosing the correct option from a set of possible options. Here, that probability is translated into an estimation of drift rate such that the speed with which activity accumulates to threshold increases as the probability of selecting the correct option increases. Therefore, to estimate time to threshold, distance is divided by speed where distance is determined by threshold level and speed is determined by drift rate (Heath, & Wilcox, 1990; Nosofsky, & Palmeri, 1997; Schneider, & Logan, 2005). Thus, if T is threshold level, C is the weight of the evidence for correct option (i.e., amount of activity transmitted to a given key representation), and A is the weight of evidence for all alternative options, the formula to estimate the duration of the key selection process is as follows:

$$\frac{T}{\frac{C}{C + A}} \quad \text{which is reduced as} \quad \frac{T(C + A)}{C}$$

Key selection triggers the motor command for the corresponding keystroke movement. Keystroke execution time is determined by movement initiation and duration times. Note that the initiation of a keystroke movement is subject to the availability of the requisite effector. For example, if the finger that executes keystroke *n* also executes keystroke *n*-1, keystroke *n* would not be able to begin until keystroke *n*-1 is finished.

However, if keystroke *n*-1 does not obstruct keystroke *n*, keystroke *n* would be able to begin while keystroke *n*-1 is still in progress. Therefore, if S is the time it takes to start a movement prescribed by a selected motor command and D is the delay imposed by the time it takes the requisite effector to become available, then keystroke initiation time is simply S + D. So then to estimate keystroke execution time the duration of a keystroke movement (M) is simply added to the initiation time as follows: (S + D) + M.

The two-step model of inner loop processing proposed here is an elaboration of Logan and Crump's (2011) two-loop theory of skilled typing. Recall that, in their model, the outer loop is assumed to rely on language generation or comprehension mechanisms to produce a series of words to type, which it then sends one word at a time to the inner loop, which produces a series of keystrokes. In the case of transcribing discrete words, reaction time (RT) refers to the interval that spans the presentation of a to-be-typed word and the time at which the key for the first letter of the word is pressed. Therefore, RT is determined by the duration of outer loop processing plus the duration of inner loop processing for the first letter's keystroke. Inter-keystroke intervals (IKSI) between successive non-first letter keystrokes are determined by inner loop processing, which includes key selection duration plus keystroke execution time: ((T(C + A))/C) + ((S + D) + M).

Alternative Models

The two-step model of inner loop processing introduced above outlines a serial processing structure for key selection and keystroke execution. In it, information is passed from stage to stage through a single channel in which key selection is processed first and then its output is fed into the keystroke execution process, which is accomplished second. However, as discussed in the Processing Structures: An Introduction section, other processing structures (i.e., independent parallel self-terminating, independent parallel exhaustive, and co-active), which receive information through multiple channels and process the information received through those channels either co-actively or independently in parallel, are also possible. Therefore, it is important to consider alternative models of inner loop processing in which a common processing stage could receive key selection-related information through one channel and keystroke execution-related information through a separate channel and process those sources of information simultaneously: It is assumed that the key selection process must inform the keystroke execution process in order to produce an intended and directed keystroke movement. Therefore, neither of the parallel processing structures would be appropriate for inner loop processing because, in those structures, information received through separate channels is processed independently and, as such, do not inform or influence each other. Moreover, even if the processing of the channels were not independent, the self-terminating structure would still not be appropriate. In self-terminating structures, information is transmitted to the next stage once the processing in one channel finishes. Correct typing requires the accurate completion of both key selection and keystroke execution. Therefore, the only remaining possibility for concurrent processing would be a co-active processing structure.

Rumelhart and Norman's (1982) interactive activation model of skilled typing is consistent with a co-active processing structure in that, in their model, the production of keystroke depends on the joint contributions from top-down (i.e., selection-related) and bottom-up (i.e., execution-related) influences. That is, the intent to type a word activates a corresponding ordered set of keystroke schemata in parallel. Each key schema inhibits all of the following schemata, producing an activation gradient (Estes, 1972). The keystroke movements that correspond to all of the active schemata are initiated in parallel in proportion to each schema's activity level. At the same time, information about the current position of each effector also influences the extent to which each key schema is active, such that a schema's activity level increases as an effector gets closer to its target key's position. A keystroke is ultimately produced when the effector that is executing the keystroke movement that corresponds to the most active key schema is within some predetermined bound of its target. Here, top-down selection-related information from the initial activation of keystroke schemata and bottom-up execution-related information from finger proximities to target keys are processed co-actively within a single stage which results in the pressing of a key.

CHAPTER II

THE PRESENT STUDY: INTRODUCTION AND DESIGN

An additive factors analysis should be able to distinguish between the possibility that key selection and keystroke execution are serial, independent processes, as the two-step model of inner loop processing proposes, or are two components of a co-active process, as Rumelhart and Norman's (1982) interactive activation model proposes: If key selection and keystroke execution are independent and serial, factors that selectively influence either key selection or keystroke execution will have additive effects on typing performance. However, if key selection and keystroke execution are processed co-actively, the effects of selective factors will be over-additive on typing performance.

Guarding against Misleading Additive Effects

Recall that while additive effects are typically indicative of factors affecting serial independent processes, it is also possible that additive effects could result from factors affecting a common process (i.e., a misleading additive effect). Therefore, it is important to guard against this possibility. Below, I discuss how this was accomplished in the present study.

Additive factors analyses typically assess the effects of two factors (i.e., Factor X and Factor Y), which each have two levels, Fast (F) and Slow (S), on task RT. Level F corresponds to the manipulation that is expected to result in a relative decrease in RT, while Level S corresponds to the manipulation that is expected to result in a relative increase in RT. The four factorial combinations of Factors X and Y are thus X_{Fast} Y_{Fast}, X_{Fast} Y_{Slow}, X_{Slow} Y_{Fast}, and X_{Slow} Y_{Slow}. This annotation is simplified as FF, FS, SF, SS, respectively. The average RTs of these four conditions can be input into a mean interaction contrast equation (i.e., MIC = SS – SF – FS + FF) to assess whether factor effects are additive (i.e., MIC = 0), under-additive (i.e., MIC <0), or over-additive. The MIC equation was used to model the effects that two levels of two factors would have on key selection duration, which again is estimated by the following formula: T(C+A)/C, where T is threshold, C is the weight of the evidence for the correct option, and A is the weight of the evidence for all alternative options.

Experimental factors can influence the duration of the key selection process in one of three ways: 1) By affecting threshold levels: As threshold level decreases, time to threshold decreases and, as such, the duration of the choice process decreases. 2) By affecting the weight of the evidence for the correct option: Increasing the weight of the evidence for the correct option will increase the numerator of Luce, which will increase drift rate and shorten the duration of the choice process. 3) By affecting the weight of the evidence for the alternative options: Increasing the weight of the evidence for alternative options will increase the denominator of Luce, which will decrease drift rate and lengthen the duration of the choice process.

An Example Case. If Factor X is expected to reduce threshold level and, as such, reduce key selection duration, levels of this factor would be represented as follows:

Fast: $\frac{(T-X)(C + A)}{C}$ Slow: $\frac{T(C + A)}{C}$

If Factor Y is expected to increase the denominator of Luce and, as such, increase key selection duration, levels of this factor would be represented as follows:

Fast: $\frac{T(C + A)}{C}$ Slow: $\frac{T(C + A + Y)}{C}$

Therefore, the four factorial combinations of Factors X and Y would be as follows:

$$\text{FF: } \frac{(T-X)(C+A)}{C} \quad \text{FS: } \frac{(T-X)(C+A+Y)}{C} \quad \text{SF: } \frac{T(C+A)}{C} \quad \text{SS: } \frac{T(C+A+Y)}{C}$$

When these terms are input into the mean interaction contrast equation (i.e., MIC = SS-FS-SF+SS), the result is XY/C. Therefore, Factors X and Y would interact in an over-additive manner.

There are 15 combinations of ways in which two factors could affect key selection duration. The factor effects that would be produced in these 15 cases are modeled in Appendix A. Twelve of these 15 possible combinations produce over-additive effects. The remaining 3 cases produce misleading additive effects. These cases are instances in which both factors only affect the denominator of Luce or both only influence threshold additively (via increase or decrease), rather than multiplicatively. Therefore, the possibility of misleading additive effects being produced in the present study was minimized by manipulating factors that would avoid these problem cases.

Manipulated Factors

One factor that should influence the duration of the key selection process is number of orthographic neighbors. Orthographic neighbors are words that are spelled the same as a target word except for one change. Because orthographic neighbors are near matches for the results of the visual analysis to the target word, the number of orthographic nodes that receive activity should increase as the target word's number of orthographic neighbors increases. Activity filters down through the network from the active orthographic representation nodes to their corresponding key representations, so the amount of activity transmitted to the correct key representation (i.e., the strength of the evidence for the correct option) should increase as the target word's number of orthographic neighbors increases. This increase would then be reflected in an increase in the numerator of Luce, which would increase drift rate and, as such, reduce key selection duration. This decrease in key selection duration would be reflected in measures of typing speed, such as inter-keystroke intervals (IKSIs). Indeed, IKSIs have been found to decrease as a word's number of orthographic neighbors increases (Scaltritti, Arfe, Torrance, & Peressotti, 2016).

A second factor that should influence the duration of the key selection process is the number of meanings that are associated with the target word's orthography. The number of meanings words have determine their ambiguity. That is, words that have multiple meanings are considered ambiguous, while words that have one meaning are considered unambiguous. The effect of word ambiguity on typing performance has not yet been investigated. However, ambiguity effects have been found in naming tasks (Gottlob, Goldinger, Stone, & Van Orden, 1999; Hino, Lupker, & Pexman, 2002), such that words that have multiple meanings are responded to faster than words that have only one meaning. In the present study, typing speed is expected to increase as a word's number of meanings increases: Because each meaning is assumed to have its own semantic and pointer representations, the number of pointers transmitting activity to the appropriate key representations are assumed to increase as the target word's number of meanings increases. As the amount of activity increases, the strength of the evidence for the correct key option increases, which increases the numerator of Luce. As a result, drift rate would increase and, as such, shorten the duration of key selection, which would be reflected in decreased IKSIs.

One factor that should affect keystroke movement duration is keystroke distance. Keystrokes are aimed movements and, as such, are subject to Fitts' Law (1954). Fitts' law states that movement time is a function of the distance an effector must traverse to reach a target and on the size of the target such that movements to targets that are more distant and smaller are slower than movements to targets that are more proximal and larger. On QWERTY keyboards, lettered keys are the same size, so keystroke duration should depend on the distance a finger must traverse to reach its target. Indeed, previous typing studies have found that IKSIs do increase as keystroke distances increase (Coover, 1923; Gentner, 1983; Rumelhart, & Norman, 1982).

Another factor that should affect keystroke execution duration is movement type (i.e., flexion versus extension). Researchers have found that it takes a longer amount of time to flex a finger than to extend it, perhaps because finger flexions must overcome increased tendon tension relative to finger extensions (Keenan, Santos, Venkadesan, & Valero-Cuevas, 2009; Nelson, Treaster, & Marras, 2000; Sommerich, Marras, & Parnianpour, 1995). If finger flexions are slower than finger extensions in keystroke movements, IKSIs to top row keys would be shorter than IKSIs to bottom row keys. An analysis of IKSIs to top and bottom row keys from a previous study (Logan, Ulrich, & Lindsey, 2016) indicated that top row IKSIs were, in fact, significantly shorter than bottom row IKSIs, $F = 114.8$, $p < .001$.

Effect of Execution Factors on a Common Process

It may be the case that key selection and keystroke execution are processed within a common stage. If so, aspects of keystroke movements would influence the key choice process. These “aspects” could be on-line information about the current position or movement of an effector or representational information about the movements necessary to press specific keys. If keystroke distance information is encoded in key representations, it is plausible that biases could develop for home row keys, which have short distances, over top and bottom row keys, which have long distances. Biases influence threshold levels (Wagenmakers, 2009), so it is possible that keystroke distance could affect threshold. Alternatively, if key representations code distance or movement information or both, associations could develop among key representations that are similarly distant or require similar movements, allowing activation to spread to similar alternative options. If this were the case, the keystroke execution factors would affect drift rates via the denominator of Luce. Recall, that the three cases that produce misleading additive effects are when both factors only affect the denominator of Luce or when both only influence threshold additively (via increase or decrease), rather than multiplicatively. Therefore, because both selection factors are expected to affect the numerator of Luce, if the selection and execution factors affect a common process, the effects of selection and execution factors should be over-additive rather than additive regardless of whether the execution factors affect threshold levels or the denominator of Luce.

Other Factor Considerations

The additive factors methodology requires that factors have selective influence (i.e., Factor X affects Stage A but not Stage B and Factor Y affects Stage B but not Stage A). There are at least three variables that could affect either key selection or keystroke execution or both: Word frequency, bigram frequency, and letter frequency. Word frequency could affect the duration of key selection by affecting drift rate via the numerator of Luce: If the strengths of the associations that link pointer representations to key representations depend on how frequently a given word is typed, the amount of activity transmitted to the key representations would increase as word frequency increases. Thus, as word frequencies increase, the weight of the evidence for the correct option (i.e., the numerator of Luce) would increase, which would increase drift rate. This would reduce the duration of the selection process and would be manifested as shorter IKSIs. Indeed, IKSIs have been found to decrease as word frequency increases (Fendrick, 1937; Pinet, Ziegler, Alario, 2016; Scatritti, et al., 2016; Shaffer, 1973; West, & Sabban, 1982).

Bigram frequency could also affect key selection duration by affecting drift rate via the numerator of Luce: As typists become skilled, associations may develop among consecutively chosen key representations, the strengths of which would depend on the bigram frequencies of pairs of letters. If this were the case, the amount of activity a key representation receives would depend on how often that key is selected after the previously selected key. Thus, as bigram frequency increases, the weight of the evidence for the correct option would increase, which would reduce drift rate and shorten the duration of the key selection process. Indeed, many typing studies have found that IKSIs decrease as bigram frequency increases (Gentner, Larochelle, & Grudin, 1988; Grudin, & Larochelle, 1982; Salthouse, 1984; Scatritti, et al., 2016; Terzuolo, & Viviani, 1980).

Letter frequency could affect the duration of key selection by influencing threshold levels: Threshold levels, or the distance between starting point and threshold level, are affected by aspects of a task that correspond to biases within the processing structure that are present before the presentation of the current stimulus (Wagenmakers, 2009). More frequent letters are chosen more often than less frequent letters, so biases may develop accordingly as typists acquire skill. If such a bias does exist, the distance between starting point and threshold levels for each key representation's stochastic accumulator would decrease as the letter frequency increases. This would reduce the duration of the key selection process and be manifested as shorter IKSIs. Indeed, IKSIs have been found to decrease as letter frequency increases (Fendrick, 1937).

In addition to affecting the duration of the key selection process, word, bigram, and letter frequencies could also affect keystroke execution time: Movements that are frequently executed in specific sequences become co-articulated with extensive practice. Execution times for co-articulated movements are shorter than execution times for movement sequences that are not co-articulated (Gentner, 1981; Gordon, Casabona, & Soechting, 1994; Jordan, 1995; Rumelhart, & Norman, 1982). Therefore, because these frequency variables could influence either key selection or keystroke execution or both they would be considered non-selective factors. As a result, it is necessary to ensure that word, bigram, and letter frequencies do not differ between conditions in the present study.

Word length could affect the duration of key selection by affecting drift rate via the denominator of Luce: Because activity is assumed to flow from pointer representations to all of the requisite key representations, the number of alternative key options that receive activity increases with word length. As a result, the value of the denominator of Luce increases, which slows drift rate. This would increase the duration of the key selection process and would be manifested as longer IKSIs. Indeed, IKSIs have been found to increase as word length increases (Scaltritti, et al., 2016; Sternberg, Monsell, Knoll, & Wright, 1978; Yamaguchi, et al., 2013). Therefore, if stimulus word lengths varied, it could influence the duration of key selection. However, word length would not be an appropriate factor to manipulate in the present study because if the execution factors also affect the denominator of Luce, it could produce misleading additive effects. Thus, all stimulus words in the present study will be 5 letters in length.

Semantic neighborhood size is likely to affect key selection by influencing the strength of the evidence for alternative key options: Activity is assumed to spread out laterally from nodes representing the presented word's meaning or meanings to the nodes of associated semantic representations. Those nodes transmit activity to their associated pointers, which transmit activity to their associated key representations. Therefore, as a word's semantic neighborhood increases, the strength of the evidence for alternative options (i.e., the denominator of Luce) increases. As discussed above, it would not be appropriate to manipulate the denominator of Luce because it could lead to misleading additive effects. As such, stimulus words' semantic neighborhood size will need to be controlled. In the present study, semantic neighborhood size of stimulus words will be estimated by the number of free associate responses as listed in the USF norms database (Nelson, McEvoy, & Schreiber, 1998).

Method

Participants. The participants were 53 Vanderbilt University students and volunteers from the surrounding community who were recruited for the self-reported ability to touch-type 40 words per minute (WPM) or better. Typing skill was verified with a typing test (Logan, & Zbrodoff, 1998). One subject's typing test indicated a typing speed of only 37.9 WPM, so her experimental data was not analyzed. For the remaining 52 participants, the mean typing speed was 79.9 WPM (Range = 48.3 – 119.7) and mean accuracy was 92.1% (Range = 83.3-98.1). The average age of the participants was 21 years and on average the participants reported being able to type for 12 years. Fifty participants reported having formal touch-typing training. All participants were compensated with course credit or were paid $12 for one hour of participation. All participants had normal or corrected-to-normal vision and spoke English as a first language.

Apparatus and Procedure. The experimental procedure was as follows: First, participants gave informed consent in writing and filled out a typing survey. Then, the experimental program began, which was programmed in LIVECODE (http://livecode.com) and was presented on a flat screen computer monitor (BenQXL2411Z) that was controlled by a personal computer (ASUS M32BF). Responses were collected on standard QWERTY computer keyboards (ASUS model KB73211), which were black with black keys and white letters.

The experimental program opened up a 16.5 x 20.5 cm light gray window that was centered on a black screen. All experiment text was displayed in black Helvetica font. Task instructions were presented in 20 point font. Target words and participant responses were presented in 40 point font. The experiment consisted of 5 blocks of 109 trials in which each of the 545 stimulus words were presented, one word per trial, in random order for each participant. At the beginning of each trial, a central fixation mark was presented for 250ms. Then, after a 250ms blank interval, a target word was displayed centrally 6 cm below the top of the program window. Participants were instructed to type the presented word as quickly and accurately as possible and to press the space bar to move on to the next trial. The participants' input was echoed on the screen 4 cm below the presented target word. The inter-trial interval was 500ms. At the end of the 5 blocks, the experimental programmed took participants through the typing test (Logan, & Zbrodoff, 1998).

Stimuli. Two selection factors are manipulated in the present study: Number of orthographic neighbors and number of meanings. The number of orthographic neighbors for each word was determined by averaging the number listed in the CLEARPOND (Marian, V.,Bartolotti, J., Chabal, S., & Shook, A., 2012) and English Lexicon Project (Balota, D.A., Yap, M.J., Cortese, M.J., Hutchison, K.A., Kessler, B., Loftis, B., Neely, J.H., Nelson, D.L., Simpson, G.B., & Treiman, R., 2007) databases. Words with many orthographic neighbors (i.e., 4.5 or more) are used for the fast level of this factor and words with few orthographic neighbors (i.e., 2.5 or less) are used for the slow level of this factor.

The number of meanings for each word was determined by the number of definitions and senses listed in the Wordsmyth database (Parks, R., Ray, J., & Bland, S., 1998). Words that have multiple unrelated definitions are considered homographs, while words that have many similar meanings are considered polysemious. Ambiguity effects have been found for both homographic and polysemious words (Klien, & Murphy, 2001; 2002; Berretta, Fiorentino, & Peoppel, 2005). Therefore, the fast level of this factor consists of words that have either more than one definition or one definition and more than two senses. The slow level of this factor consists of words with one definition and two or fewer senses. The number of meanings, or ambiguity, effects observed in linguistic studies are typically only found for words with very low frequencies (Hino, & Lupker, 1996; Jastrembski, 1981; Lichacz, Herdman, Lefevre, & Baird, 1999; Rubenstein, Lewis, & Rubenstein, 1971). Therefore, all stimulus words in the present study have a Kuèera–Francis frequency of 60 occurrences per million or less (MRC Psycholinguistic Database; Coltheart, 1981).

Two execution factors are also assessed in the present study: Movement type and keystroke distance. As discussed above, finger extensions are expected to have shorter durations than finger flexions, so movements to top row keys are used for the fast level of the movement type factor and movements to bottom row keys are used for the slow level. Precise keystroke distances depend on which fingers typists use to strike each key. Standard touch-typing protocol specifies which finger should press each key. However, while most of today's college students received formal touch-typing training in grade school, a recent video analysis found that 14 of 24 typists who claimed to use standard typing protocol failed to actually do so in practice (Logan, et al., 2016). If subjects use different typing strategies, precise keystroke distances would have to be determined on a case by case basis, making it virtually impossible to balance factor level conditions appropriately. In addition, because self-report is often inaccurate and video verification is prohibitively time consuming, using only subjects that adhere to touch-typing protocol is also not a viable alternative. Therefore, in the present study, keystroke distance factor levels (i.e., long versus short) are approximated by key row. The distance between the center of the home row and the center of either the top or bottom row is approximately 20 mm. If it is assumed that all typists, regardless of typing strategy, adhere to a "home position" in which their fingers hover above the middle row and that they return to this home position between each keystroke (Soecthing, & Flanders, 1992), top and bottom row keystrokes would require traversing longer distances than home row keystrokes. As a result, Fitts' Law (1954) would suggest that top and bottom row IKSIs should be longer than home row IKSIs (Logan, 2003).

To assess whether IKSIs do in fact differ depending on the row to which a keystroke is directed and whether such differences depend on typing strategy, I analyzed data from Logan et al. (2016). Logan and colleagues asked typists whether they use standard touch-typing protocol and then conducted a video analysis to assess what kind of typing strategy the typists actually used while they transcribed a paragraph. I analyzed the IKSIs of keystrokes from correctly typed words by first averaging IKSIs for each letter, not including the first keystroke of each word, and then averaging over the letters in each row for each subject (see Table 1). A 3 within (Row: Home vs. Top vs. Bottom) x 2 between (Typing Strategy: Standard vs. Non-Standard) analysis of variance (ANOVA) indicated that IKSIs varied significantly by row, $F(2,92) = 25.3$, $p < .001$, $\eta^2 = .346$, and by typing strategy, $F(1,46) = 4.4$, $p < .05$, $\eta^2 = .088$. The interaction between row and strategy was not statistically significant, $F(2,92) = 1.9$, $p < .153$, $\eta^2 = .026$. This result indicates that typing strategy does not change the effect of row on IKSI. I then conducted a contrast analysis comparing home row IKSIs (Mean = 137 ms) versus top (Mean = 145 ms) and bottom (Mean = 175 ms) row IKSIs, $F = 87.1$, $p < .001$, which indicated that home row IKSIs are significantly shorter than top and bottom row IKSIs, as would be expected if home row keystroke distances are shorter than top and bottom row keystroke distances.

Table 1. *Average IKSI by Row for Standard and Non-Standard Typists (Logan, et al., 2016)*

	Top Row	Home Row	Bottom Row
Standard	132	127	150
Non-Standard	148	140	181

The word stimuli in the present study were chosen so as to populate the 2 (# of Orth. NBRs: Many vs. Few) x 2 (# of Meanings: Many vs. Few) x 3 (Row: Top vs. Home vs. Bottom) design for four sets of additive factors analyses. The first two analyses assess the effects of the factors on the speed and accuracy with which typists produce the 1st keystroke of transcribed words. The benefit of this analysis is that it is assumed that participants will begin their first keystroke movement from the home position and, as such, movements to top row keys will require finger extensions, movements to bottom row keys will require finger flexions, movements to top and bottom row keys will have long distances, and movements to home row keys will have short distances. In addition, it is unclear whether within-word keystrokes may be considered independent or not. If they are dependent, it would pose a problem for statistical analysis of the data. However, this potential problem is avoided by only analyzing one keystroke per word.

Unfortunately, information on the number of associates was not available for all of the stimulus words. Therefore, whether number of associates is controlled for or not is an additional factor in the experiment design. For the 1st keystroke analyses, there are 20 words per cell in the 2 (# of Associates: Controlled vs. Uncontrolled) x 2 (# of Meanings: Many vs. Few) x 2 (# of Orth. NBRs: Many vs. Few) x 3 (Row: Top vs. Home vs. Bottom) design. The verification of stimuli characteristics to ensure that number of meanings, number of senses, and number of orthographic neighbors do differ between factor levels when appropriate and that number of associates, word frequencies, and first letter frequencies do not differ between groups was accomplished through a set of Analyses of Variance (ANOVAs). The means and standard deviations for the number of meanings in each cell of the design are listed in Table 2. The associated ANOVA table is in Table 3. The means and standard deviations for the number of senses in each cell of the design are listed in Table 4. The associated ANOVA table is in Table 5. The means and standard deviations for the number of orthographic neighbors in each cell of the design are listed in Table 6. The associated ANOVA table is in Table 7. The means and standard deviations for the number of associates for the half of the stimuli for which number of associates were controlled are listed in Table 8. The associated ANOVA table is in Table 9. The means and standard deviations for the word frequencies for each cell in the design are listed in Table

10. The associated ANOVA table is in Table 11. The means and standard deviations for the first letter frequencies (http://norvig.com/mayzner.html) are listed in Table 12. The associated ANOVA table is in Table 13. Information about the stimuli used for the first 1st keystroke of the word analysis is listed in Appendix B.

Table 2. *Means and standard deviations of the number of definitions for the 1st keystroke stimuli*

				Mean	St. Dev.
Controlled Associates	Many Meanings	Few Orth. NBRs	Top	1.3	0.5
			Home	1.4	0.7
			Bottom	1.3	0.6
		Many Orth. NBRs	Top	1.4	0.5
			Home	1.5	0.5
			Bottom	1.3	0.4
	Few Meanings	Few Orth. NBRs	Top	1	0
			Home	1	0
			Bottom	1	0
		Many Orth. NBRs	Top	1	0
			Home	1	0
			Bottom	1	0
Uncontrolled Associates	Many Meanings	Few Orth. NBRs	Top	1.3	0.4
			Home	1.3	0.5
			Bottom	1.5	0.7
		Many Orth. NBRs	Top	1.5	0.6
			Home	1.4	0.5
			Bottom	1.5	0.7
	Few Meanings	Few Orth. NBRs	Top	1	0
			Home	1	0
			Bottom	1	0
		Many Orth. NBRs	Top	1	0
			Home	1	0
			Bottom	1	0

Table 3. *ANOVA table for the number of definitions for the 1st keystroke stimuli*

	df	MSe	*F*	*p*
Controlled Associates (C)	1,19	.1	<1	.340
Meanings (M)	1,19	.2	93.1	<.001
Orth. NBRs (ON)	1,19	.2	<1	.389
Row (R)	2,38	.2	<1	.939
C x M	1,19	.1	1.0	.340
C x ON	1,19	.2	<1	.745
C x R	2,38	.1	1.6	.215
M x ON	1,19	.2	<1	.389
M x R	2,38	.1	<1	.939
ON x R	2,38	.2	<1	.878
C x M x ON	1,19	.2	<1	.745
C x M x R	2,38	.1	1.6	.215
C x ON x R	2,38	.1	<1	.836
M x ON x R	2,38	.2	<1	.878
C x M x ON x R	2,38	.1	<1	.836

Table 4. *Means and standard deviations of the number of senses for the 1st keystroke stimuli*

				Mean	St. Dev.
Controlled Associates	Many Meanings	Few Orth. NBRs	Top	4.8	1.9
			Home	4.4	1.0
			Bottom	4.6	1.1
		Many Orth. NBRs	Top	5.2	1.8
			Home	5.8	4.3
			Bottom	5.1	2.5
	Few Meanings	Few Orth. NBRs	Top	1.6	0.5
			Home	1.5	0.5
			Bottom	1.5	0.5
		Many Orth. NBRs	Top	1.9	0.7
			Home	1.5	0.5
			Bottom	1.8	0.4
Uncontrolled Associates	Many Meanings	Few Orth. NBRs	Top	4.7	2.5
			Home	4.9	2.7
			Bottom	3.7	0.7
		Many Orth. NBRs	Top	4.8	1.7
			Home	5.1	1.7
			Bottom	3.8	1.5
	Few Meanings	Few Orth. NBRs	Top	1.7	0.5
			Home	1.6	0.5
			Bottom	1.5	0.5
		Many Orth. NBRs	Top	1.9	0.6
			Home	1.4	0.5
			Bottom	1.5	0.5

Table 5. *ANOVA table for the number of senses for the 1st keystroke stimuli*

	df	MSe	*F*	*p*
Controlled Associates (C)	1,19	3.6	2.4	.140
Meanings (M)	1,19	1.7	706.1	<.001
Orth. NBRs (ON)	1,19	2.6	3.0	.098
Row (R)	2,38	2.7	2.6	.085
C x M	1,19	3.1	2.2	.152
C x ON	1,19	1.9	2.5	.133
C x R	2,38	2.6	1.4	.261
M x ON	1,19	2.8	1.2	.287
M x R	2,38	2.6	2.8	.076
ON x R	2,38	2.1	<1	.887
C x M x ON	1,19	2.5	<1	.610
C x M x R	2,38	2.5	<1	.455
C x ON x R	2,38	2.4	<1	.815
M x ON x R	2,38	2.3	1.1	.332
C x M x ON x R	2,38	2.3	<1	.748

Table 6. *Means and standard deviations of the number of orthographic neighbors for the 1st keystroke stimuli*

				Mean	St. Dev.
Controlled Associates	Many Meanings	Few Orth. NBRs	Top	1.5	0.8
			Home	1.5	0.7
			Bottom	1.8	0.7
		Many Orth. NBRs	Top	7.6	2.2
			Home	7.2	1.9
			Bottom	7.2	2.3
	Few Meanings	Few Orth. NBRs	Top	1.2	0.7
			Home	1.4	0.8
			Bottom	1.4	0.8
		Many Orth. NBRs	Top	7.1	2.8
			Home	6.8	2.0
			Bottom	6.6	1.8
Uncontrolled Associates	Many Meanings	Few Orth. NBRs	Top	0.7	0.8
			Home	1.3	0.8
			Bottom	1.6	0.9
		Many Orth. NBRs	Top	7.3	1.9
			Home	7.4	2.0
			Bottom	7.1	1.9
	Few Meanings	Few Orth. NBRs	Top	1.5	0.9
			Home	1.6	0.8
			Bottom	1.5	0.8
		Many Orth. NBRs	Top	7.3	3.1
			Home	7.5	2.7
			Bottom	6.5	1.7

Table 7. *ANOVA table for the number of orthographic neighbors for the 1st keystroke stimuli*

	df	MSe	*F*	*p*
Controlled Associates (C)	1,19	2.7	<1	.956
Meanings (M)	1,19	3.2	<1	.385
Orth. NBRs (ON)	1,19	3.2	1236.9	<.001
Row (R)	2,38	2.4	<1	.691
C x M	1,19	3.4	2.0	.179
C x ON	1,19	2.4	<1	.585
C x R	2,38	2.0	<1	.445
M x ON	1,19	2.7	1.4	.255
M x R	2,38	4.0	<1	.618
ON x R	2,38	2.3	2.9	.068
C x M x ON	1,19	3.1	<1	.666
C x M x R	2,38	1.9	<1	.611
C x ON x R	2,38	2.8	<1	.825
M x ON x R	2,38	3.6	<1	.949
C x M x ON x R	2,38	2.6	<1	.949

Table 8. *Means and standard deviations of the number of associates for the 1st keystroke stimuli*

			Mean	St. Dev.
Many Meanings	Few Orth. NBRs	Top	14.4	5.9
		Home	15.7	2.8
		Bottom	15.8	5.0
	Many Orth. NBRs	Top	15.5	4.4
		Home	12.4	3.6
		Bottom	14.7	4.8
Few Meanings	Few Orth. NBRs	Top	14.4	5.4
		Home	13.6	3.6
		Bottom	13.3	5.0
	Many Orth. NBRs	Top	15.0	5.4
		Home	13.6	4.5
		Bottom	13.3	4.0

Table 9. *ANOVA table for the number of associates for the 1st keystroke stimuli*

	df	MSe	*F*	*p*
Meanings (M)	1,19	14.6	3.3	.087
Orth. NBRs (ON)	1,19	26.8	<1	.486
Row (R)	2,38	17.8	1.1	.334
ON x M	1,19	19.0	1.3	.268
ON x R	1,19	25.3	<1	.533
M x R	2,38	19.9	1.7	.205
M x ON x R	2,38	23.2	<1	.481

Table 10. *ANOVA table for the word frequencies for the 1st keystroke stimuli*

	df	MSe	*F*	*p*
Controlled Associates (C)	1,19	139.3	3.6	.074
Meanings (M)	1,19	168.7	<1	.517
Orth. NBRs (ON)	1,19	170.6	<1	.465
Row (R)	2,38	122.0	1.1	.331
C x M	1,19	169.3	1.5	.239
C x ON	1,19	86.8	<1	.726
C x R	2,38	136.0	1.5	.245
M x ON	1,19	161.4	<1	.594
M x R	2,38	146.6	<1	.914
ON x R	2,38	113.3	<1	.776
C x M x ON	1,19	150.5	<1	.714
C x M x R	2,38	145.9	<1	.878
C x ON x R	2,38	175.9	<1	.827
M x ON x R	2,38	203.2	<1	.870
C x M x ON x R	2,38	140.1	<1	.925

Table 11. *Means and standard deviations of the word frequencies for the 1st keystroke stimuli*

				Mean	St. Dev.
Controlled Associates	Many Meanings	Few Orth. NBRs	Top	12.6	13.7
			Home	11.4	11.9
			Bottom	13.3	11.9
		Many Orth. NBRs	Top	14.1	11.9
			Home	12.1	13.7
			Bottom	12.6	12.6
	Few Meanings	Few Orth. NBRs	Top	12.5	13.2
			Home	10.4	16.5
			Bottom	11.0	13.5
		Many Orth. NBRs	Top	9.8	9.5
			Home	9.2	12.6
			Bottom	10.0	11.1
Uncontrolled Associates	Many Meanings	Few Orth. NBRs	Top	10.8	12.8
			Home	10.9	14.8
			Bottom	7.4	9.3
		Many Orth. NBRs	Top	8.0	8.6
			Home	11.2	11.7
			Bottom	7.0	11.8
	Few Meanings	Few Orth. NBRs	Top	13.2	9.7
			Home	11.7	16.3
			Bottom	6.9	7.3
		Many Orth. NBRs	Top	9.8	10.4
			Home	9.7	12.1
			Bottom	8.1	10.9

Table 12. *ANOVA table for the letter frequencies for the 1st keystroke stimuli*

	df	MSe	*F*	*p*
Controlled Associates (C)	1,19	3.1	<1	.997
Meanings (M)	1,19	6.8	<1	.975
Orth. NBRs (ON)	1,19	5.7	<1	.576
Row (R)	2,38	6.8	<1	.397
C x M	1,19	4.8	<1	.340
C x ON	1,19	5.2	<1	.448
C x R	2,38	5.3	1.6	.218
M x ON	1,19	6.6	1.6	.222
M x R	2,38	4.3	<1	.797
ON x R	2,38	4.5	<1	.408
C x M x ON	1,19	6.2	<1	.799
C x M x R	2,38	6.0	1.5	.233
C x ON x R	2,38	6.7	1.1	.332
M x ON x R	2,38	3.4	3.2	.053
C x M x ON x R	2,38	4.3	1.1	.359

Table 13. *Means and standard deviations of the letter frequencies for the 1st keystroke stimuli*

				Mean	St. Dev.
Controlled Associates	Many Meanings	Few Orth. NBRs	Top	4.3	2.8
			Home	4.8	1.9
			Bottom	3.3	1.4
		Many Orth. NBRs	Top	3.5	2.7
			Home	3.9	1.6
			Bottom	4.1	1.6
	Few Meanings	Few Orth. NBRs	Top	4.2	3.0
			Home	4.4	2.8
			Bottom	3.4	2.4
		Many Orth. NBRs	Top	4.7	3.5
			Home	4.7	2.1
			Bottom	3.7	1.2
Uncontrolled Associates	Many Meanings	Few Orth. NBRs	Top	4.9	2.8
			Home	4.5	2.5
			Bottom	4.0	2.3
		Many Orth. NBRs	Top	4.2	3.3
			Home	3.8	2.4
			Bottom	3.7	1.2
	Few Meanings	Few Orth. NBRs	Top	4.4	2.2
			Home	3.0	0.9
			Bottom	4.6	1.9
		Many Orth. NBRs	Top	3.4	2.4
			Home	4.5	2.4
			Bottom	4.0	1.9

The third and fourth sets of additive factors analyses assess the effects of the factors on the speed and accuracy of non-first letter keystrokes. For these analyses, performance on one top row keystroke, one home row keystroke, and one bottom row keystroke from each word are assessed. Here, typing speed is measured by inter-keystroke intervals (IKSIs) between the analyzed keystroke (*n*) and the keystroke that precedes it (*n*-1). The benefit of this analysis is that IKSIs are determined by only inner loop processing, so it is a purer measurement of key selection and keystroke execution processes than RT. For this analysis, word stimuli were required to have at least one appropriate top, home, and bottom row keystroke. A keystroke was considered "appropriate" if it could be reasonably assumed that the keystroke began from as close to a home position as possible based on the characteristics of the preceding keystroke. Again, this is an important consideration so as to ensure that top row keystrokes require finger extensions, bottom row keystrokes require finger flexions, top and bottom row keystroke distances are long, and home row keystroke distances are short. It is assumed that the hand not currently executing a keystroke will return to a home position (Soetching, & Flanders, 1992), so if keystroke *n* and keystroke *n*-1 were typed with different hands as determined by standard touch-typing protocol, keystroke *n* was considered appropriate. If keystroke *n* and keystroke *n*-1 were typed with the same hand as determined by standard touch-typing protocol and keystroke *n*-1 was a home row key, then keystroke *n* was considered appropriate.

There are 12 non-first letter keystrokes per cell in the 2 (# of Associates: Controlled vs. Uncontrolled) x 2 (# of Meanings: Many vs. Few) x 2 (# of Orth. NBRs: Many vs. Few) x 3 (Row: Top vs. Home vs. Bottom) design. The verification of stimuli characteristics to ensure that number of meanings, number of senses, and number of orthographic neighbors do differ between factor levels when appropriate and that number of associates, word frequencies, bigram frequencies between keystroke *n* and keystroke *n*-1, and letter frequencies for keystroke *n* do not differ between groups was accomplished through a set of ANOVAs. Note that values for number of definitions, number of senses, number of orthographic neighbors, word frequencies, and number of associates will not vary by row because one top, home, and bottom row keystroke is analyzed from each word. Therefore, those analyses were conducted at the word level.

The means and standard deviations for the number of meanings in each cell of the design are listed in Table 14. The associated ANOVA table is in Table 15. The means and standard deviations for the number of senses in each cell of the design are listed in Table 16. The associated ANOVA table is in Table 17. The means and standard deviations for the number of orthographic neighbors in each cell of the design are listed in Table 18. The associated ANOVA table is in Table 19. The means and standard deviations for the number of associates for the half of the stimuli for which number of associates were controlled are listed in Table 20. The associated ANOVA table is in Table 21. The means and standard deviations for the word frequencies for each cell in the design are listed in Table 22. The associated ANOVA table is in Table 23. The means and standard deviations for bigram frequencies (Jones, & Mewhort, 2004) are listed in Table 24. The associated ANOVA table is in Table 25. The means and standard deviations for the letter frequencies of the analyzed keystrokes are listed in Table 26. The associated ANOVA table is in Table 27. Information about the stimuli used for the 3 keystrokes per word analysis is listed in Appendix C.

Table 14. *Means and standard deviations of the number of definitions for the non-first letter stimuli*

			Mean	St. Dev.
Associates Controlled	Many Meanings	Many Orth. NBRs	1.6	0.8
		Few Orth. NBRs	1.2	0.6
	Few Meanings	Many Orth. NBRs	1	0
		Few Orth. NBRs	1	0
Associates Uncontrolled	Many Meanings	Many Orth. NBRs	1.4	0.5
		Few Orth. NBRs	1.3	0.5
	Few Meanings	Many Orth. NBRs	1	0
		Few Orth. NBRs	1	0

Table 15. *ANOVA table for the number of definitions for the non-first letter stimuli*

	df	MSe	*F*	*p*
Controlled Associates (C)	1,11	.2	<1	.830
Meanings (M)	1,11	.2	17.8	<.001
Orth. NBRs (ON)	1,11	.2	2.4	.152
C x M	1,11	.2	<1	.830
C x ON	1,11	.1	<1	.389
M x ON	1,11	.2	2.4	.152
C x M x ON	1,11	.41	<1	.389

Table 16. *Means and standard deviations of the number of senses for the non-first letter stimuli*

			Mean	St. Dev.
Associates Controlled	Many Meanings	Many Orth. NBRs	4.8	2.5
		Few Orth. NBRs	4.2	0.9
	Few Meanings	Many Orth. NBRs	1.5	0.5
		Few Orth. NBRs	1.6	0.5
Associates Uncontrolled	Many Meanings	Many Orth. NBRs	4.2	1.3
		Few Orth. NBRs	3.7	0.9
	Few Meanings	Many Orth. NBRs	1.5	0.5
		Few Orth. NBRs	1.4	0.5

Table 17. *ANOVA table for the number of senses for the non-first letter stimuli*

	df	MSe	*F*	*p*
Controlled Associates (C)	1,11	.9	3.0	.112
Meanings (M)	1,11	1.6	110.9	<.001
Orth. NBRs (ON)	1,11	1.8	1.1	.312
C x M	1,11	.8	1.8	.203
C x ON	1,11	1.5	<1	.999
M x ON	1,11	1.4	1.5	.246
C x M x ON	1,11	1.0	<1	.689

Table 18. *Means and standard deviations of the number of orthographic neighbors for the non-first letter stimuli*

			Mean	St. Dev.
Associates Controlled	Many Meanings	Many Orth. NBRs	6.8	1.6
		Few Orth. NBRs	1.3	0.8
	Few Meanings	Many Orth. NBRs	6.2	1.3
		Few Orth. NBRs	1.6	0.6
Associates Uncontrolled	Many Meanings	Many Orth. NBRs	6.0	1.3
		Few Orth. NBRs	1.8	0.6
	Few Meanings	Many Orth. NBRs	6.5	1.1
		Few Orth. NBRs	1.3	1.0

Table 19. *ANOVA table for the number of orthographic neighbors for the non-first letter stimuli*

	df	MSe	*F*	*p*
Controlled Associates (C)	1,11	1.4	<1	.707
Meanings (M)	1,11	.4	<1	.688
Orth. NBRs (ON)	1,11	1.9	300.5	<.001
C x M	1,11	1.5	<1	.773
C x ON	1,11	1.1	<1	.373
M x ON	1,11	.9	<1	.876
C x M x ON	1,11	1.1	4.6	.054

Table 20. *Means and standard deviations of the number of associates for the non-first letter stimuli*

		Mean	St. Dev.
Many Meanings	Many Orth. NBRs	14.1	5.4
	Few Orth. NBRs	15.3	4.3
Few meanings	Many Orth. NBRs	12.3	4.1
	Few Orth. NBRs	14.0	4.3

Table 21. *ANOVA table for the number of associates for the non-first letter stimuli*

	df	MSe	*F*	*p*
Meanings (M)	1,11	27.7	<1	.357
Orth. NBRs (ON)	1,11	23.7	1.2	.297
M x ON	1,11	12.0	<1	.839

Table 22. *Means and standard deviations of the word frequencies for the non-first letter stimuli*

			Mean	St. Dev.
Associates Controlled	Many Meanings	Many Orth. NBRs	12.5	9.5
		Few Orth. NBRs	12.1	8.8
	Few Meanings	Many Orth. NBRs	11.6	13.4
		Few Orth. NBRs	6.9	15.0
Associates Uncontrolled	Many Meanings	Many Orth. NBRs	9.7	14.0
		Few Orth. NBRs	11.7	13.4
	Few Meanings	Many Orth. NBRs	6.2	12.2
		Few Orth. NBRs	10.4	19.5

Table 23. *ANOVA table for the word frequencies for the non-first letter stimuli*

	df	MSe	*F*	*p*
Controlled Associates (C)	1,11	198.6	<1	.661
Meanings (M)	1,11	110.6	1.6	.231
Orth. NBRs (ON)	1,11	300.2	<1	.938
C x M	1,11	151.6	<1	.899
C x ON	1,11	180.6	1.0	.333
M x ON	1,11	156.6	<1	.840
C x M x ON	1,11	166.0	<1	.550

Table 24. *Means and standard deviations of the bigram frequencies for the non-first letter stimuli*

				Mean	St. Dev.
Controlled Associates	Many Meanings	Many Orth. NBRs	Top	3385	3314
			Home	3694	3240
			Bottom	5465	5617
		Few Orth. NBRs	Top	4289	4747
			Home	3387	2663
			Bottom	4393	6525
	Few Meanings	Many Orth. NBRs	Top	4654	4498
			Home	3667	3245
			Bottom	7609	8583
		Few Orth. NBRs	Top	3971	3841
			Home	4667	3035
			Bottom	3503	5573
Uncontrolled Associates	Many Meanings	Many Orth. NBRs	Top	4553	3296
			Home	3618	3084
			Bottom	7732	8286
		Few Orth. NBRs	Top	2978	3782
			Home	5128	7928
			Bottom	5345	7462
	Few Meanings	Many Orth. NBRs	Top	5219	4171
			Home	2830	1769
			Bottom	4583	5586
		Few Orth. NBRs	Top	2593	2868
			Home	4660	4034
			Bottom	6352	7215

Table 25. *ANOVA table for the bigram frequencies for the non-first letter stimuli*

	df	MSe	*F*	*p*
Controlled Associates (C)	1,11	2.304e+7	<1	.678
Meanings (M)	1,11	3.868e+7	<1	.971
Orth. NBRs (ON)	1,11	2.563e+7	<1	.440
Row (R)	2,22	3.816e+7	2.3	.121
C x M	1,11	1.930e+7	1.1	.313
C x ON	1,11	2.441e+7	<1	.699
C x R	2,22	2.948e+7	<1	.816
M x ON	1,11	2.684e+7	<1	.989
M x R	2,22	2.961e+7	<1	.945
ON x R	2,22	2.874e+7	1.4	.261
C x M x ON	1,11	2.956e+7	<1	.399
C x M x R	2,22	2.705e+7	<1	.898
C x ON x R	2,22	1.599e+7	2.1	.146
M x ON x R	2,22	2.139e+7	<1	.687
C x M x ON x R	2,22	2.448e+7	1.2	.333

Table 26. *Means and standard deviations of the letter frequencies for the non-first letter stimuli*

				Mean	St. Dev.
Controlled Associates	Many Meanings	Many Orth. NBRs	Top	4.9	2.8
			Home	3.5	2.8
			Bottom	4.3	1.8
		Few Orth. NBRs	Top	5.4	2.7
			Home	4.7	2.7
			Bottom	3.3	2.0
	Few Meanings	Many Orth. NBRs	Top	5.9	3.9
			Home	4.7	2.7
			Bottom	4.6	2.4
		Few Orth. NBRs	Top	6.2	2.5
			Home	5.5	2.2
			Bottom	3.4	2.5
Uncontrolled Associates	Many Meanings	Many Orth. NBRs	Top	5.0	2.6
			Home	4.4	2.8
			Bottom	5.6	2.0
		Few Orth. NBRs	Top	5.3	2.6
			Home	4.0	2.8
			Bottom	4.6	2.4
	Few Meanings	Many Orth. NBRs	Top	6.1	3.9
			Home	4.7	2.9
			Bottom	4.1	2.0
		Few Orth. NBRs	Top	4.4	3.8
			Home	4.8	2.4
			Bottom	5.1	2.3

Table 27. *ANOVA table for the letter frequencies for the non-first letter stimuli*

	df	MSe	*F*	*p*
Controlled Associates (C)	1,11	5.5	<1	.754
Meanings (M)	1,11	5.6	1.3	.271
Orth. NBRs (ON)	1,11	14.3	<1	.908
Row (R)	2,22	9.5	3.1	.069
C x M	1,11	5.6	1.0	.341
C x ON	1,11	6.7	<1	.462
C x R	2,22	8.1	1.6	.216
M x ON	1,11	6.1	<1	.812
M x R	2,22	3.7	1.2	.322
ON x R	2,22	3.3	2.2	.139
C x M x ON	1,11	7.6	<1	.650
C x M x R	2,22	8.7	<1	.912
C x ON x R	2,22	4.1	2.9	.076
M x ON x R	2,22	11.6	<1	.621
C x M x ON x R	2,22	10.0	<1	.517

CHAPTER III

THE PRESENT STUDY: ANALYSIS AND DISCUSSION

First Keystroke Analyses

Here, I assess factor effects on the speed and accuracy with which the first keystrokes of transcribed words are produced. Typing speed is measured by RT, which is the interval between the onset of the target word and the time at which the computer registers the first keystroke. For the speed analysis, RTs are assessed if the entire word is typed correctly. For the accuracy analysis, if the first keystroke registered by the computer was the first letter of the word, it was counted as correct. Otherwise, it was counted as incorrect. Proportion correct were log transformed and submitted to the same additive factors analyses as the speed data. As with RT, log proportion correct data should indicate additive effects when factors affect independent serial stages and interactive effects when they affect a common processing stage (Schweikert, 1985).

As discussed previously, it is possible that words' number of associates could affect key selection duration, so effort was made to ensure that number of associates did not differ between conditions. However, the limited number of low frequency 5-letter words with normed free associates data were further constrained by the necessity of having to balance a number of variables across conditions. As a result, the maximum number of words found to meet the requisite criteria for each of the cells in the 2 (# of meanings: Many vs. Few) x 2 (# of Orth. NBRs.: Many vs. Few) x 3 (Row: Top vs. Home vs. Bottom) design was 20. In an effort to increase the number of times typing performance could be assessed per condition, an additional 20 words per cell for which number of associates were not controlled were also included as stimuli. To determine whether controlling for number of associates affected first keystroke performance, 2 (# of Associates: Controlled vs. Uncontrolled) x 2 (# of Meanings: Many vs. Few) x 2 (# of Orth. NBRs: Many vs. Few) x 3 (Row: Top vs. Home vs. Bottom) ANOVAs were conducted on the RT (see Tables 28 and 29) and log proportion correct (see Tables 30 and 31) data. The results indicated that controlling for number of associates did not have a significant main effect on RT, $F(1,51)<1$, $p= .717$. It also did not affect the interaction between number of meanings and number of orthographic neighbors, $F(1,51)<1$, $p= .357$, or the interaction between number of orthographic neighbors and row, $F(2,102)<1$, $p= .540$. However, it did affect the interaction between number of meanings and row significantly, $F(2,102)=18.9$, $p< .001$. Controlling for number of associates did not have a significant main effect on log proportion correct, $F(1,51)<1$, $p= .497$, nor did it significantly affect the interaction between number of meanings and number of orthographic neighbors, $F(1,51)=2.3$, $p= .137$, number of meanings and row, $F(2,102)=2.5$, $p= .087$, or number of orthographic neighbors and row, $F(2,102)<1$, $p= .696$.

Table 28. *ANOVA table for the RTs of the (2x2x2x3) analysis*

	df	MSe	*F*	*p*	η^2
Controlled Associates (C)	1,51	591.3	<1	.717	.003
Meanings (M)	1,51	883.8	4.7	.035	.084
Orth. NBRs (ON)	1,51	2181.0	126.6	<.001	.713
Row (R)	2,102	4102.2	6.6	.002	.115
C x M	1,51	606.4	8.0	.007	.135
C x ON	1,51	801.4	5.4	.024	.095
C x R	2,102	583.3	1.5	.236	.028
M x ON	1,51	1035.1	<1	.481	.010
M x R	2,102	738.8	1.8	.177	.033
ON x R	2,102	809.4	4.2	.018	.076
C x M x ON	1,51	939.2	<1	.357	.017
C x M x R	2,102	784.2	18.9	<.001	.271
C x ON x R	2,102	670.6	<1	.540	.012
M x ON x R	2,102	735.1	37.8	<.001	.426
C x M x ON x R	2,102	860.0	9.4	<.001	.155

Table 29. *Means and standard deviations of RTs for the (2x2x2x3) analysis*

				Mean	St. Dev.
Controlled Associates	Many Meanings	Few Orth. NBRs	Top	603	78
			Home	628	97
			Bottom	601	75
		Many Orth. NBRs	Top	661	101
			Home	643	109
			Bottom	620	87
	Few Meanings	Few Orth. NBRs	Top	623	76
			Home	615	90
			Bottom	608	72
		Many Orth. NBRs	Top	638	91
			Home	657	108
			Bottom	660	92
Uncontrolled Associates	Many Meanings	Few Orth. NBRs	Top	607	74
			Home	634	100
			Bottom	611	94
		Many Orth. NBRs	Top	652	93
			Home	635	103
			Bottom	643	90
	Few Meanings	Few Orth. NBRs	Top	620	70
			Home	627	99
			Bottom	605	73
		Many Orth. NBRs	Top	641	83
			Home	662	133
			Bottom	625	85

Table 30. *ANOVA table for the Log Proportions Correct of the (2x2x2x3) 1st keystroke analysis*

	df	MSe	*F*	*p*	η^2
Controlled Associates (C)	1,51	.001	<1	.497	.009
Meanings (M)	1,51	.002	2.5	.124	.046
Orth. NBRs (ON)	1,51	.002	14.2	<.001	.218
Row (R)	2,102	.002	18.5	<.001	.266
C x M	1,51	.002	2.3	.134	.043
C x ON	1,51	.002	3.8	.058	.069
C x R	2,102	.002	<1	.928	.001
M x ON	1,51	.002	<1	.977	.000
M x R	2,102	.002	3.8	.027	.069
ON x R	2,102	.002	3.2	.043	.060
C x M x ON	1,51	.002	2.3	.137	.043
C x M x R	2,102	.002	2.5	.087	.047
C x ON x R	2,102	.002	<1	.696	.007
M x ON x R	2,102	.002	<1	.864	.003
C x M x ON x R	2,102	.002	1.3	.280	.025

Table 31. *Means and standard deviations of Log Proportions Correct for the (2x2x2x3) 1st keystroke analysis*

				Mean	St. Dev.
Controlled Associates	Many Meanings	Few Orth. NBRs	Top	-.019	.033
			Home	-.032	.044
			Bottom	-.015	.028
		Many Orth. NBRs	Top	-.044	.056
			Home	-.041	.060
			Bottom	-.031	.044
	Few Meanings	Few Orth. NBRs	Top	-.024	.038
			Home	-.055	.064
			Bottom	-.023	.037
		Many Orth. NBRs	Top	-.026	.032
			Home	-.058	.055
			Bottom	-.043	.054
Uncontrolled Associates	Many Meanings	Few Orth. NBRs	Top	-.031	.041
			Home	-.045	.048
			Bottom	-.022	.040
		Many Orth. NBRs	Top	-.024	.035
			Home	-.038	.050
			Bottom	-.037	.056
	Few Meanings	Few Orth. NBRs	Top	-.024	.039
			Home	-.045	.054
			Bottom	-.018	.029
		Many Orth. NBRs	Top	-.032	.034
			Home	-.047	.063
			Bottom	-.033	.043

The above analyses suggest that controlling for number of associates does influence some of the effects that are crucial for the current study. Therefore, all further analyses are conducted twice: Data from only the stimuli for which number of associates are controlled are assessed to address the need for experimental control. Data collapsed over stimuli for which number of associates were and were not controlled are assessed to address the desire for increased experimental power. Two (# of Meanings: Many vs. Few) x 2 (# of Orth. NBRs: Many vs. Few) x 3 (Row: Top vs. Home vs. Bottom) ANOVAs were conducted on RTs from the stimuli for which number of associates were controlled (see Table 32) as well as from the data collapsed across stimuli for which number of associates were and were not controlled (see Tables 33 and 34). Two (# of Meanings: Many vs. Few) x 2 (# of Orth. NBRs: Many vs. Few) x 3 (Row: Top vs. Home vs. Bottom) ANOVAs were also conducted on log proportions correct from the stimuli for which number of associates were controlled (see Table 35) as well as from the data collapsed across stimuli for which number of associates were and were not controlled (see Tables 36 and 37).

Main Effects. Number of meanings and number of orthographic neighbors were both expected to affect key selection by influencing the strength of the evidence for the correct option, which would affect the numerator of Luce such that drift rate would increase and key selection duration would decrease as the number of meanings and orthographic neighbors increase. Number of meanings had a significant main effect on RT when number of associates were controlled, $F(1,51)=13.5$, $p<.001$, and regardless of whether number of associates were controlled, $F(1,51)=5.7$, $p=.021$. It also had a significant main effect on log proportions correct when number of associates were controlled, $F(1,51)=4.5$, $p<.039$, but not when collapsing over stimuli for which number of associates were and were not controlled, $F(1,51)=2.5$, $p=.124$. Number of orthographic neighbors had a significant main effect on RT when number of associates were controlled, $F(1,51)=106.4$, $p<.001$, and regardless of whether number of associates were controlled, $F(1,51)=123.6$, $p<.001$. It also had a significant main effect on log proportion correct when number of associates were controlled, $F(1,51)=15.0$, $p<.001$, and regardless of whether number of associates were controlled or not, $F(1,51)=14.3$, $p<.001$. These findings indicate that RTs are faster for words that have more meanings than for words that have fewer meanings and for words that have more orthographic neighbors than for words that have fewer orthographic neighbors.

There was a significant main effect of row on RT when number of associates were controlled, $F(2,102)=4.6, p=.012$, and regardless of whether number of associates were controlled or not, $F(2,102)=6.3, p=.003$. Row also had a significant main effect on log proportion correct when number of associates were controlled, $F(2,102)=9.1$, $p<.001$, and regardless of whether number of associates were controlled or not, $F(2,102)=18.4$, $p<.001$. Recall that row measures both of the execution factors (i.e., keystroke distance and movement type). Regarding the keystroke distance factor, typing speed was expected to be slower for keystrokes to more distant keys than for keystrokes to more proximal keys (Fitts, 1954). It was assumed that typists would maintain a “home position” such that their hands would hover above the home row. If this were the case, RTs to home row keys, which have short keystroke distances, would be faster than RTs to top or bottom row keys, which have longer keystroke distances. However, the data indicate that RTs were faster for long distance keystrokes to top and bottom row keys than for short distance keystrokes to home row keys. It is unclear why this pattern of results occurred. Regarding the movement type factor, typing speed was expected to be faster for keystrokes that require extensions (i.e., top row keys) than for keystrokes that require flexions (i.e., bottom row keys). However, the data again indicated that the opposite was true in the current data. The prediction was based on the results of motor control studies (Keenan, et al., 2009; Nelson, et al., 2000; Sommerich, et al., 1995), which suggested that it takes longer to overcome the increased tendon tension of flexion than to extend a finger. However, keystroke movements do not require complete extensions and flexions, so it is possible that the unexpected findings are due to differences in task requirements.

Table 32. *ANOVA table for RTs (Associated Controlled)*

	df	MSe	*F*	*p*	η^2
Meanings (M)	1, 52	660.6	13.5	<.001	.210
Orth. NBRs (ON)	1, 52	1642.7	106.4	<.001	.676
Row (R)	2,102	2175.4	4.6	.012	.083
ON x M	1, 52	888.2	1.5	.229	.028
M x R	2, 102	734.2	13.8	<.001	.213
ON x R	2, 102	531.0	1.7	.196	.031
M x ON x R	2, 102	812.7	29.1	<.001	.363

Table 33. *Means and standard deviations of RTs (Associates Controlled and Uncontrolled)*

			Mean	St. Dev.
Many Meanings	Few Orth. NBRs	Top	606	75
		Home	631	96
		Bottom	607	81
	Many Orth. NBRs	Top	655	91
		Home	640	103
		Bottom	631	86
Few Meanings	Few Orth. NBRs	Top	622	71
		Home	621	93
		Bottom	607	71
	Many Orth. NBRs	Top	643	85
		Home	659	114
		Bottom	643	87

Table 34. *ANOVA table for RTs (Associates Controlled and Uncontrolled)*

	df	MSe	*F*	*p*	η^2
Meanings (M)	1, 52	448.6	5.7	.021	.100
Orth. NBRs (ON)	1, 52	1099.1	123.6	<.001	.708
Row (R)	2,102	2071.4	6.3	.003	.110
M x ON	1, 52	451.3	1.3	.252	.026
M x R	2, 102	274.3	1.0	.356	.020
ON x R	2, 102	327.7	5.0	.008	.089
M x ON x R	2, 102	339.1	32.1	<.001	.386

Table 35. *ANOVA table for Log Proportions Correct for 1st Keystrokes (Associated Controlled)*

	df	MSe	*F*	*p*	η^2
Meanings (M)	1, 52	.002	4.5	.039	.081
Orth. NBRs (ON)	1, 52	.002	15.0	<.001	.228
Row (R)	2,102	.003	9.1	<.001	.151
ON x M	1, 52	.002	1.3	.255	.025
M x R	2, 102	.002	5.4	.006	.096
ON x R	2, 102	.002	1.2	.303	.023
M x ON x R	2, 102	.002	1.2	.317	.022

Table 36. *Means and standard deviations of Log Proportions Correct (Associates Controlled and Uncontrolled)*

			Mean	St. Dev.
Many Meanings	Few Orth. NBRs	Top	-.025	.026
		Home	-.038	.037
		Bottom	-.018	.025
	Many Orth. NBRs	Top	-.033	.036
		Home	-.039	.043
		Bottom	-.033	.036
Few Meanings	Few Orth. NBRs	Top	-.024	.032
		Home	-.049	.042
		Bottom	-.020	.019
	Many Orth. NBRs	Top	-.029	.023
		Home	-.052	.046
		Bottom	-.037	.032

Table 37. *ANOVA table for Log Proportions Correct* (Associates Controlled and Uncontrolled)

	df	MSe	F	p	η^2
Meanings (M)	1, 52	-.0009	2.5	.124	.046
Orth. NBRs (ON)	1, 52	-.0007	14.3	<.001	.219
Row (R)	2,102	.001	18.4	<.001	.266
M x ON	1, 52	-.0009	<1	.999	.000
M x R	2, 102	-.0007	3.6	.030	.066
ON x R	2, 102	-.0008	3.2	.044	.059
M x ON x R	2, 102	-.0009	<1	.856	.003

Interactions. The five interactions that are particularly important for the current study are number of orthographic neighbors x number of meanings, number of orthographic neighbors x keystroke distance, number of orthographic neighbors x movement type, number of meanings x keystroke distance, and number of meanings x movement type. The evidence as to whether the effects of these factors are interactive or additive are assessed via mean interaction contrast (MIC) equations, interaction statistics, and Bayes factors. The statistic for the number of meanings and number of orthographic neighbors interactions come straight from the above ANOVAs. The statistics for the remaining four interactions are derived from planned contrast comparison analyses that assess the effect of keystroke distance separately from the effect of movement type.

Contrast weights for those analyses are listed in Table 38. Bayes factors assess the likelihood of the results under the null hypothesis, that factor effects do not interact (i.e., are additive), or the alternative hypothesis, that factor effects do interact (Rouder, Speckman, Sun, Morey, & Iverson, 2009). The summary of the additive factors analyses conducted on these interactions are listed in Table 39 for the data derived from stimuli for which number of associates were controlled and in Table 40 for data collapsed over whether number of associates were controlled or not. Assessments as to the strength of the evidence derived from Bayes factors values are as suggested by Jeffreys (1961). Effect sizes are listed in Table 41.

Table 38. *Planned Contrast Comparison Weights*

	Top, Many, Hom.	Top, Many, Non-Hom.	Top, Few, Hom.	Top, Few, Non-Hom.	Home, Many, Hom.	Home, Many, Non-Hom.	Home, Few, Hom.	Home, Few, Non-Hom.	Bottom, Many, Hom.	Bottom, Many, Non-Hom.	Bottom, Few, Hom.	Bottom, Few, Non-Hom.
# of Meanings x Distance	1	-1	1	-1	-2	2	-2	2	1	-1	1	-1
# of Meanings x Movement Type	1	-1	1	-1	0	0	0	0	-1	1	-1	1
# of Orth. NBRs x Distance	1	1	-1	-1	-2	-2	2	2	1	1	-1	-1
# of Orth. NBRs x Movement Type	1	1	-1	-1	0	0	0	0	-1	-1	1	1

Table 39. *Summary of 1st Keystroke Additive Factors Analyses (Associates Controlled)*

	RT				Log Proportion Correct			
	MIC	F	p	Bayes	MIC	F	p	Bayes
# of Meanings x # of Orth. NBRs	6	1.5	.229	4.6	.0083	1.3	.255	4.9
	Over	Non-Sig		Substantial Null	Over	Non-Sig		Substantial Null
# of Meanings x KS Distance	11	5.2	.027	1.3	.0183	5.8	.020	1.6
	Over	Significant		Anecdotal Alternative	Over	Significant		Anecdotal Alternative
# of Meanings x Movement Type	25	22.1	<.001	898.3	-.0165	3.5	.067	1.7
	Over	Significant		Decisive Alternative	Under	Non-Sig		Anecdotal Alternative
# of Orth. NBRs x KS Distance	8	3.7	.06	1.7	-.0098	1.6	.211	4.1
	Over	Non-Sig		Anecdotal Null	Under	Non-Sig		Substantial Null
# of Orth. NBRs x Movement Type	-1	<1	.824	9.0	-.0045	2.6	.113	2.7
	Under	Non-Sig		Substantial Null	Under	Non-Sig		Anecdotal Alternative

Table 40. *Summary of 1st Keystroke Additive Factors Analyses (Associates Controlled and Uncontrolled)*

	RT				Log Proportion Correct			
	MIC	F	p	Bayes	MIC	F	p	Bayes
# of Meanings x # of Orth. NBRs	4	1.3	.252	4.9	-.0003	<1	.999	9.2
	Over	Non-Sig		Substantial Null	Under	Non-Sig		Substantial Null
# of Meanings x KS Distance	-1	<1	.860	9.1	.0118	6.3	.015	2.0
	Under	Non-Sig		Substantial Null	Over	Significant		Anecdotal Alternative
# of Meanings x Movement Type	4	1.5	.223	4.4	-.0055	3.4	.071	5.7
	Over	Non-Sig		Substantial Null	Under	Non-Sig		Substantial Null
# of Orth. NBRs x KS Distance	9	8.6	.005	5.4	-.00093	1.0	.322	1.8
	Over	Significant		Substantial Alternative	Under	Non-Sig		Anecdotal Null
# of Orth. NBRs x Movement Type	-5	2.0	.165	3.5	-.0095	2.7	.106	2.5
	Under	Non-Sig		Anecdotal Null	Under	Non-Sig		Anecdotal Null

Table 41. *Effect Sizes for 1st Keystroke Interaction Analyses*

		Reaction Time	Log Prop. Correct
# of Associates Controlled	# of Meanings x # of Orth. NBRs.	.170	.160
	# of Meanings x Row	.520	.326
	# of Orth. NBRs. x Row	.179	.153
# of Associates Controlled & Uncontrolled	# of Meanings x # of Orth. NBRs.	.163	.032
	# of Meanings x Row	.143	.266
	# of Orth. NBRs. x Row	.313	.250

It was expected that number of meanings and number of orthographic neighbors would both affect the key selection process. If this were the case, their effects would interact over-additively. However, the results from the RT and log proportion correct analyses on data from stimuli for which number of associates were controlled and regardless of whether number of associates were controlled (see Tables 39 and 40) all consistently suggested substantial evidence for the null hypothesis. Therefore, these findings are consistent with the conclusion that number of meanings and number of orthographic neighbors affect separate processing stages.

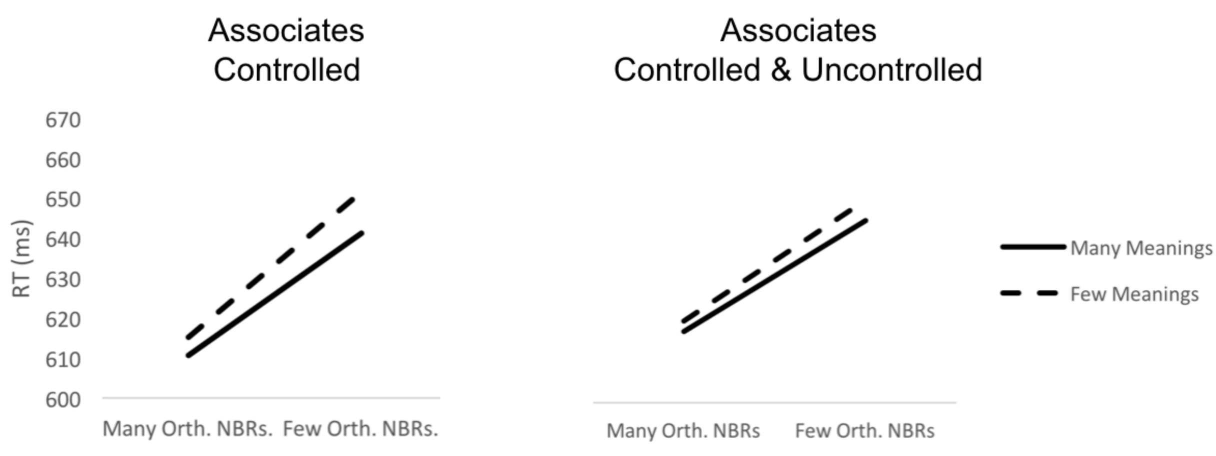

Figure 1. Effects of Number of Meanings and Number of Orthographic Neighbors on RT.

The results of the additive factors analyses on number of meanings and keystroke distance suggest that there is anecdotal evidence that the factors interact over-additively on RT when number of associates are controlled (MIC = 11; F=5.2, p=.027; Bayes = 1.3) and on log proportion correct when number of associates are controlled (MIC = .0183; F=5.8, p=.020; Bayes = 1.6) and regardless of whether number of associates are controlled (MIC = .0118; F=6.3, p=.015; Bayes = 2.0). These findings are consistent with the conclusion that number of meanings and keystroke distance affect processing that is performed within a common stage, so it is possible that keystroke distance could influence the weight of the evidence for alternative options (i.e., the denominator of Luce).

There is substantial evidence that number of meanings and keystroke distance have additive effects on RT when collapsed across whether number of associates are controlled or not (MIC = -1; F<1, p=.860; Bayes = 9.1). Recall that the reason number of associates needed to be controlled was that the factor could affect the duration of the key selection process via the drift rate by influencing the weight of the evidence for alternative options and, as such, the denominator of Luce. This is problematic because if an execution factor also influences the weight of the evidence for alternative options it could result in a misleading additive effect. Therefore, if keystroke distance does in fact affect the weight of the evidence for alternative options, the substantial evidence for the null hypothesis when RT data are collapsed over whether number of associates controlled or not may be attributable to a misleading additive effect.

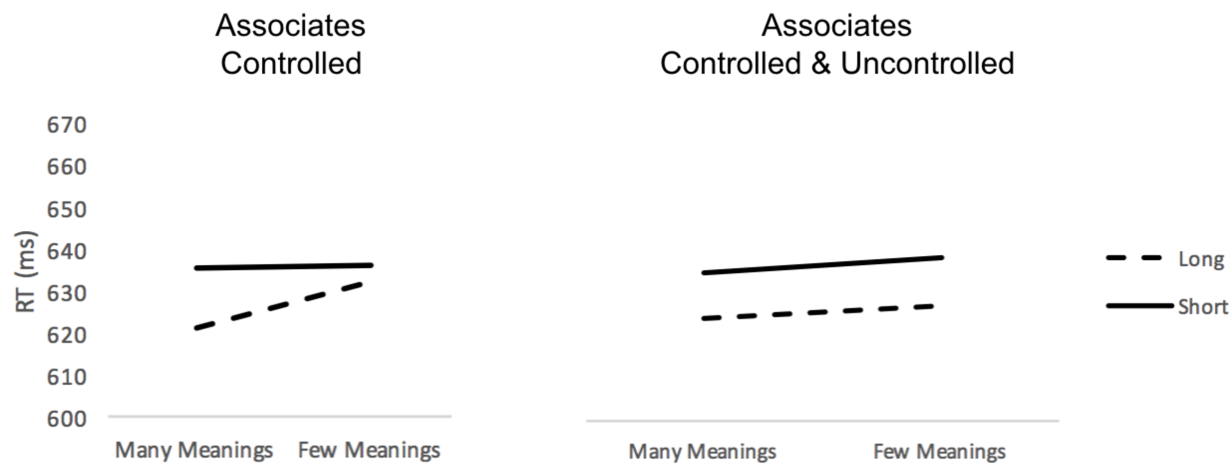

Figure 2. Effects of Number of Meanings and Keystroke Distance on RT.

The results of the additive factors analysis on number of meanings and movement type provides decisive evidence that their effects interact over-additively on RT when number of associates are controlled (MIC = 25; *F*=22.1, *p*<.001; Bayes = 898.3). However, a finding of a non-statistically significant interaction between these factors on log proportion correct provides anecdotal evidence of under-additive effects (MIC = -.0165; *F*=3.5, *p*=.067; Bayes = 1.7). It is unclear why the results of the speed and accuracy analysis are inconsistent. However, effect sizes are larger for the speed data than for the accuracy data, probably because accuracies were close to ceiling levels (Mean = 96.8%), and the Bayes factors indicate that the data provide more evidence for the speed finding than for the accuracy finding, so it is likely the case that number of meanings and movement type are over-additive. The analyses conducted on data collapsed over whether number of associates were controlled or not provide substantial evidence that number of meanings and movement type have additive effects on the speed (MIC = 4; *F*=1.5, *p*=.223; Bayes = 4.4) and accuracy (MIC = -.0055; *F*=3.4, *p*=.071; Bayes = 5.7) of first keystrokes. However, as discussed above, such findings may be due to misleading additive effects.

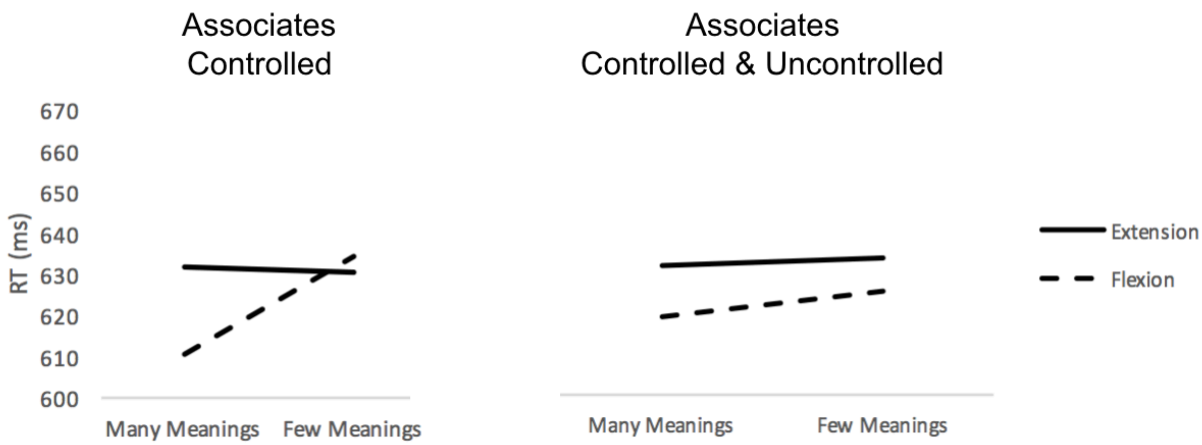

Figure 3. Effects of Number of Meanings and Movement Type on RT.

The results of the additive factors analyses conducted on number of orthographic neighbors and keystroke distance suggest that the factors have additive effects on the speed (MIC = 8; *F*=3.7, *p*=.060; Bayes = 1.7) and accuracy (MIC = -.0098; *F*=1.6, *p*=.211; Bayes = 4.1) of first keystrokes when number of associates are controlled. However, the results from the analyses conducted on the data that collapse across whether number of associates were controlled or not suggest that the factors have an over-additive effect on RT (MIC = 8; *F*=8.6, *p*=.005; Bayes = 5.4) but an additive effect on log proportion correct (MIC = -.0093; *F*=1.0, *p*=.322; Bayes = 1.8). Note that the values of the RT MICs are equivalent for when number of associates are controlled and regardless of whether number of associates are controlled or not. However, there is twice as much data when collapsing over whether number of associates are controlled or not than when only analyzing data from when number of associates are controlled and so the former analysis has more power to detect an effect than the latter analyses (see Table 41). Therefore, it is possible that number of orthographic neighbors and keystroke distance had an over-additive effect on RT when number of associates were controlled that failed to reach significance.

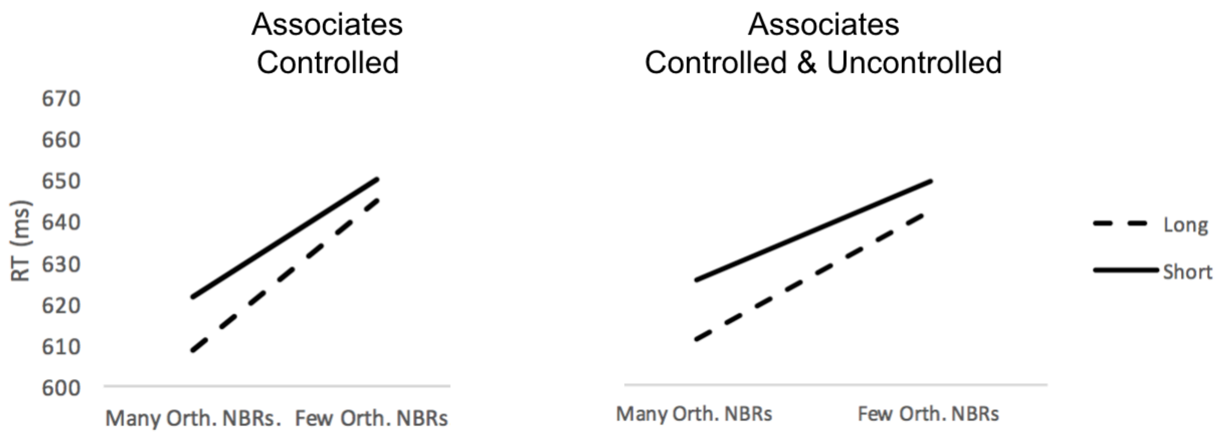

Figure 4. Effects of Number of Orthographic Neighbors and Keystroke Distance on RT.

The results of the additive factors analyses conducted on number of orthographic neighbors and movement type provide substantial evidence that the factors had additive effects on RT when number of associates were controlled (MIC = -1; F<1, p.824; Bayes = 9.0) and anecdotal evidence for additive effects on RT when collapsing over whether number of associates were controlled or not (MIC = -5; F=2.0, p=.165; Bayes = 3.5). There is anecdotal evidence that the factors had an under-additive effect on log proportion correct when number of associates were controlled (MIC = -.0045; F=2.6, p=.113; Bayes = 2.7) but that they had an additive effect when collapsing over whether number of associates were controlled or not (MIC = -.0095; F=22.1, p=2.7; Bayes = 2.5). Because evidence from the speed analysis is stronger than the evidence from the accuracy analysis, it is probably the case that number of orthographic neighbors and movement type have additive effects on the production of first keystrokes.

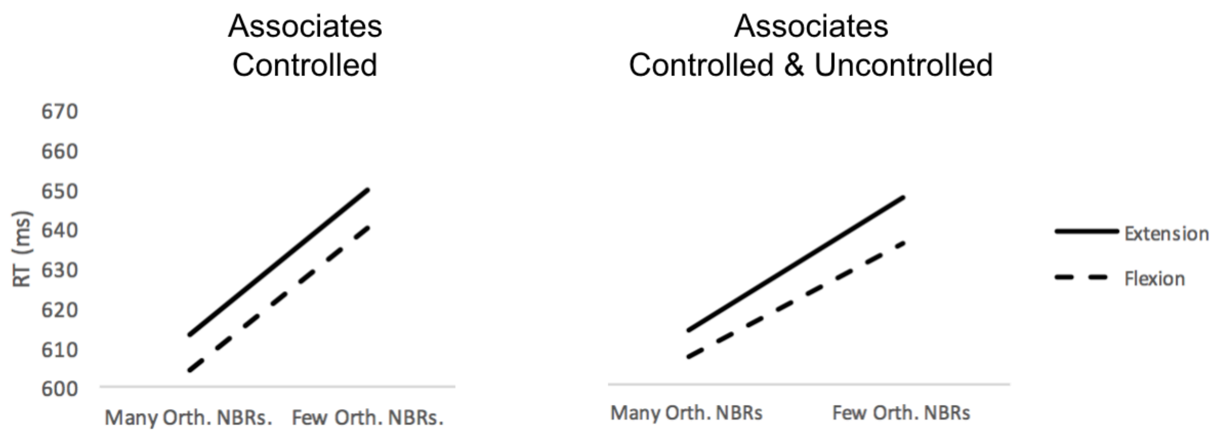

Figure 5. Effects of Number of Orthographic Neighbors and Movement Type on RT.

Discussion. The processing structure suggested by the additive factors analyses that assessed the effects of number of orthographic neighbors, number of meanings, keystroke distance, and movement type on the production of the first keystroke of transcribed words is depicted in Figure 6. The findings are consistent with the conclusion that number of orthographic neighbors and number of meanings affect processes that are independent and serial. When transcribing text, visual information must be processed and compared to stored orthographic representations, which are associated with a network of semantic representations. So, if number of orthographic neighbors and number of meanings are in fact processed by independent serial stages it would seem that the orthographic information would be processed before the semantic information when transcribing text. However, the opposite may be the case when composing text.

Further findings suggest that keystroke distance and movement type affect a stage that also processes number of meanings information, which is independent and serial of the stage that processes number of orthographic neighbors. Because keystroke distance and movement type are orthogonal it was not possible to assess whether they affect a common processing stage in the current study. Recall that first keystroke performance reflects both outer and inner loop processing. Therefore, it is possible that number of orthographic neighbors affects outer loop processing while number of meanings, keystroke distance and movement type all affect a common inner loop process.

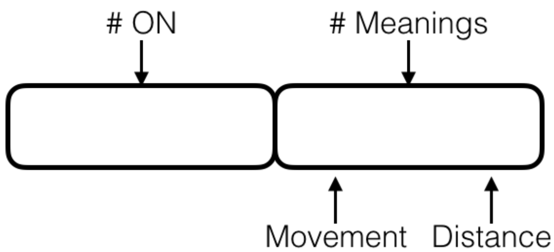

Figure 6. Processing structure suggested by analysis of first keystroke typing performance.

Non-First Letter Keystroke Analyses

The second set of analyses assessed factor effects on the speed and accuracy of non-first letter typing performance. For these analyses, three non-first letter keystrokes (i.e., one top row, one home row, and one bottom row) were chosen for analysis from each stimulus word on the basis that their characteristics adhered to the necessary constraints (see Methods section). These specific keystrokes will be referred to as target keystrokes. Typing speed was measured by inter-keystroke intervals (IKSIs), which are the intervals that span the point at which the computer registers the pressing of a target keystroke *n* and the keystroke that precedes it, *n*-1. Speed data from target keystrokes were only analyzed if the entire word was typed correctly.

When skilled typists produce typing errors, it is typically the case that a specific error is committed on a single identifiable keystroke (F. A. Logan, 1999; Salthouse, 1986; Wells, 1916), with the four main errors being insertions (e.g., border -> bor**f**der), omissions (e.g., border ->boder), replacements (e.g., border -> bo**f**der), and transpositions (e.g., border -> bo**dr**er). Indeed, the majority of the errors produced in the current dataset could be attributed to a single specific keystroke. If errors were attributed to a target keystroke, it was counted as incorrect for the accuracy analyses. These counts were tabulated for each subject for each cell of the design and were transformed to log proportions correct for further analysis. The numbers of instances for which errors could not be attributed to a single identifiable keystroke are listed in Table 42.

Table 42. *Number of words in each condition for which errors could not be attributed to a single keystroke summed over all subjects.*

		Number of Associates	
		Controlled	Uncontrolled
Many Meanings	Many Orth. NBRs.	11	6
Many Meanings	Few Orth. NBRs.	8	9
Few Meanings	Many Orth. NBRs.	7	6
Few Meanings	Few Orth. NBRs.	3	5

Two (# of Associates: Controlled vs. Uncontrolled) x 2 (# of Meanings: Many vs. Few) x 2 (# of Orth. NBRs: Many vs. Few) x 3 (Row: Top vs. Home vs. Bottom) ANOVAs were conducted on IKSIs (see Tables 43 and 44) and log proportions correct (see Tables 45 and 46) to determine whether controlling for number of associates affected typing performance. Controlling for number of associates did not have a significant main effect on IKSI, $F(1,51)=2.7$, $p=.107$, or on log proportion correct, $F(1,51)=1.6$, $p=.205$. It also did not significantly affect the interaction between number of meanings and number of orthographic neighbors, $F(1,51)<1$, $p=.473$, or between number of meanings and row, $F(2,102)=1.9$, $p=.149$, but did significantly affect the interaction between number of orthographic neighbors and row, $F(2,102)=14.1$, $p<.001$, on IKSI. Controlling for number of associates did not significantly affect the interactions between number of meanings and number of orthographic neighbors, $F(1,51)=1.5$, $p=.232$, between number of meanings and row, $F(2,102)<1$, p=.538, or between number of orthographic neighbors and row, $F(2,102)<1$, p=.734, on log proportions correct.

Table 43. *Means and standard deviations of IKSIs for the (2x2x2x3) analysis*

				Mean	St. Dev.
Controlled Associates	Many Meanings	Few Orth. NBRs	Top	129	27
			Home	106	24
			Bottom	116	29
		Many Orth. NBRs	Top	139	31
			Home	116	32
			Bottom	138	47
	Few Meanings	Few Orth. NBRs	Top	133	25
			Home	104	25
			Bottom	123	37
		Many Orth. NBRs	Top	120	30
			Home	124	33
			Bottom	147	50
Uncontrolled Associates	Many Meanings	Few Orth. NBRs	Top	119	28
			Home	102	22
			Bottom	118	27
		Many Orth. NBRs	Top	138	31
			Home	112	33
			Bottom	142	40
	Few Meanings	Few Orth. NBRs	Top	114	29
			Home	98	18
			Bottom	134	36
		Many Orth. NBRs	Top	129	29
			Home	132	48
			Bottom	133	37

Table 44. *ANOVA table for IKSIs in the (2x2x2x3) analysis*

	df	MSe	*F*	*p*	η^2
Controlled Associates (C)	1,51	436.3	2.7	.107	.050
Homograph (H)	1,51	446.0	1.2	.278	.023
Orth. NBRs (ON)	1,51	755.3	86.3	<.001	.629
Row (R)	2,102	969.8	46.9	<.001	.479
C x H	1,51	385.3	<1	.935	.000
C x ON	1,51	321.4	5.2	.027	.092
C x R	2,102	394.5	2.0	.141	.038
H x ON	1,51	341.4	1.6	.217	.030
H x R	2,102	418.7	12.6	<.001	.198
ON x R	2,102	420.4	9.4	<.001	.155
C x H x ON	1,51	212.6	<1	.473	.010
C x H x R	2,102	333.6	1.9	.149	.037
C x ON x R	2,102	409.4	14.1	<.001	.217
H x ON x R	2,102	446.7	17.8	<.001	.259
C x H x ON x R	2,102	263.5	16.7	<.001	.247

Table 45. *Means and standard deviations of log proportions correct for the (2x2x2x3) non-first letter analysis*

				Mean	St. Dev.
Controlled Associates	Many Meanings	Few Orth. NBRs	Top	-.037	.054
			Home	-.029	.049
			Bottom	-.031	.060
		Many Orth. NBRs	Top	-.025	.040
			Home	-.034	.063
			Bottom	-.057	.080
	Few Meanings	Few Orth. NBRs	Top	-.025	.044
			Home	-.025	.048
			Bottom	-.039	.054
		Many Orth. NBRs	Top	-.042	.057
			Home	-.039	.051
			Bottom	-.052	.073
Uncontrolled Associates	Many Meanings	Few Orth. NBRs	Top	-.027	.048
			Home	-.033	.063
			Bottom	-.018	.036
		Many Orth. NBRs	Top	-.038	.063
			Home	-.031	.056
			Bottom	-.069	.078
	Few Meanings	Few Orth. NBRs	Top	-.027	.052
			Home	-.020	.045
			Bottom	-.024	.043
		Many Orth. NBRs	Top	-.024	.043
			Home	-.042	.057
			Bottom	-.033	.060

Table 46. *ANOVA table for log proportions correct for the (2x2x2x3) non-first letter analysis*

	df	MSe	*F*	*p*	η^2
Controlled Associates (C)	1,51	.003	1.6	.205	.031
Meanings (M)	1,51	.003	<1	.337	.018
Orth. NBRs (ON)	1,51	.004	12.8	<.001	.201
Row (R)	2,102	.004	3.1	.048	.058
C x M	1,51	.003	2.2	.145	.041
C x ON	1,51	.003	<1	.527	.008
C x R	2,102	.002	<1	.444	.016
M x ON	1,51	.004	<1	.844	.001
M x R	2,102	.002	<1	.488	.014
ON x R	2,102	.003	4.8	.011	.085
C x M x ON	1,51	.005	1.5	.232	.028
C x M x R	2,102	.003	<1	.538	.012
C x ON x R	2,102	.003	<1	.734	.006
M x ON x R	2,102	.002	5.9	.004	.103
C x M x ON x R	2,102	.003	1.8	.165	.035

As with the first keystroke analyses, four 2 (# of Meanings: Many vs. Few) x 2 (Number of Orth. NBRs.: Many vs. Few) x 3 (Row: Top vs. Home Vs. Bottom) ANOVAs were conducted on the non-first letter data. One assessed factor effects on the IKSIs for data from stimuli for which number of associates were controlled (see Table 47). One assessed factor effects on the IKSI data collapsed across whether number of associates were controlled or not (see Tables 48 and 49). One assessed factor effects on log proportions correct when number of associates were controlled (see Table 50). One assessed factor effects on log proportions correct collapsing over whether number of associates were controlled or not (see Tables 51 and 52).

Table 47. *ANOVA table for IKSIs analysis (Associated Controlled)*

	df	MSe	*F*	*p*	η^2
Meanings (M)	1, 52	359.2	<1	.425	.013
Orth. NBRs (ON)	1, 52	655.4	35.1	<.001	.408
Row (R)	2,102	833.6	27.8	<.001	.352
ON x M	1, 52	251.3	2.2	.140	.042
M x R	2, 102	310.2	9.7	<.001	.160
ON x R	2, 102	318.7	26.6	<.001	.343
M x ON x R	2, 102	339.1	12.3	<.001	.194

Table 48. *RT Means and standard deviations of IKSIs (Associated Controlled and Uncontrolled)*

			Mean	St. Dev.
Many Meanings	Few Orth. NBRs	Top	125	26
		Home	104	20
		Bottom	117	26
	Many Orth. NBRs	Top	140	31
		Home	117	32
		Bottom	141	40
Few Meanings	Few Orth. NBRs	Top	125	26
		Home	101	20
		Bottom	127	33
	Many Orth. NBRs	Top	125	28
		Home	127	37
		Bottom	139	39

Table 49. *ANOVA table for IKSIs (Associated Controlled and Uncontrolled)*

	df	MSe	F	p	η^2
Meanings (M)	1, 52	208.0	<1	.742	.002
Orth. NBRs (ON)	1, 52	398.1	87.4	<.001	.631
Row (R)	2,102	436.4	50.6	<.001	.498
ON x M	1, 52	175.9	4.6	.037	.083
M x R	2, 102	176.6	12.7	<.001	.199
ON x R	2, 102	220.4	10.1	<.001	.165
M x ON x R	2, 102	201.2	14.6	<.001	.222

Table 50. *ANOVA table for log proportions correct for non-first letter keystrokes (Associated Controlled)*

	df	MSe	F	p	η^2
Meanings (M)	1, 52	.003	<1	.729	.002
Orth. NBRs (ON)	1, 52	.005	3.8	.058	.069
Row (R)	2,102	.003	3.7	.027	.068
ON x M	1, 52	.004	<1	.466	.010
M x R	2, 102	.003	<1	.976	.000
ON x R	2, 102	.003	1.4	.254	.026
M x ON x R	2, 102	.003	2.0	.145	.037

Table 51. *RT Means and standard deviations of log proportions correct for non-first letter analysis (Associated Controlled and Uncontrolled)*

			Mean	St. Dev.
Many Meanings	Few Orth. NBRs	Top	-.023	.029
		Home	-.032	.031
		Bottom	-.040	.040
	Many Orth. NBRs	Top	-.039	.050
		Home	-.027	.037
		Bottom	-.022	.030
Few Meanings	Few Orth. NBRs	Top	-.032	.036
		Home	-.032	.039
		Bottom	-.033	.043
	Many Orth. NBRs	Top	-.062	.055
		Home	-.033	.041
		Bottom	-.030	.042

Table 52. *ANOVA table for log proportion correct of non-first letter keystrokes (Associated Controlled and Uncontrolled)*

	df	MSe	*F*	*p*	η^2
Meanings (M)	1, 52	.001	4.5	.039	.081
Orth. NBRs (ON)	1, 52	.001	1.3	.265	.024
Row (R)	2,102	.002	2.3	.108	.043
ON x M	1, 52	.002	3.8	.058	.068
M x R	2, 102	.001	3.0	.054	.056
ON x R	2, 102	.001	10.4	<.001	.169
M x ON x R	2, 102	.001	<1	.780	.005

Main Effects. Number of orthographic neighbors had a significant main effect on IKSI both when number of associates were controlled, $F(1,51)=35.1$, $p<.001$, and regardless of whether number of associates were controlled, $F(1,51)=87.4$, $p<.001$, such that non-first letter keystrokes were faster within words that had many orthographic neighbors than within words that had few orthographic neighbors. Number of orthographic neighbors did not have a significant main effect on log proportion correct when number of associates were controlled, $F(1,51)=3.8$, $p=.058$, nor when collapsing over whether number of associates were controlled or not, $F(1,51)=1.3$, $p=.265$. Number of meanings did not have a significant main effect on IKSI when number of associates were controlled, $F(1,51)<1$,

p=.425, nor when collapsing over whether number of associates were controlled or not, $F(1,51)<1$, p=.742. Number of meanings also did not have a significant main effect on log proportion correct when number of associates were controlled, $F(1,51)<1$, p=.729, but did have a significant main effect when collapsing over whether number of associates were controlled or not, $F(1,51)=4.5$, p=.039.

Row had a significant main effect on IKSI when number of associates were controlled, $F(2,102)=27.8$, $p<.001$, and regardless of whether number of associates were controlled, $F(2,102)=50.6$, $p<.001$. Unlike in the first keystroke data, the effect of keystroke distance on non-first letter keystrokes was in the expected direction, such that typing speeds were faster for keystrokes to more proximal keys than for keystrokes to more distant keys. Row had a significant main effect on log proportions correct when number of associates were controlled, $F(2,102)=3.7$, p=.027, but not when collapsing over whether number of associates were controlled or not, $F(2,102)=2.3$, p=.108.

Interactions. As with the first keystroke data, a series of additive factors analyses were conducted on the five relevant interactions for the non-first letter data. A summary of the additive factors analyses conducted on data from stimuli for which number of associates were controlled is listed Table 53. A summary of the additive factors analyses conducted on data collapsing over whether number of associates were controlled or not is listed in Table 54. Effect sizes for the relevant interactions are listed in Table 55.

Table 53. *Summary of Non-First Letter Additive Factors Analyses (Associates Controlled)*

	IKSI				Log Proportion Correct			
	MIC	F	p	Bayes	MIC	F	p	Bayes
# of Meanings x # of Orth. NBRs	-4	2.2	.140	3.2	-.0053	<1	.466	7.1
	Under	Non-Sig		Anecdotal Null	Under	Non-Sig		Substantial Null
# of Meanings x KS Distance	-3	<1	.362	6.1	.0008	<1	.873	9.1
	Under	Non-Sig		Substantial Null	Over	Non-Sig		Substantial Null
# of Meanings x Movement Type	16	20.1	<.001	445.3	.0055	<1	.925	9.1
	Over	Significant		Decisive Alternative	Over	Non-Sig		Substantial Null
# of Orth. NBRs x KS Distance	-4	2.0	.163	3.5	.0008	<1	.873	9.1
	Under	Non-Sig		Anecdotal Null	Over	Non-Sig		Substantial Null
# of Orth. NBRs x Movement Type	25	49.0	<.001	2,303,552	-.0125	2.5	.120	2.7
	Over	Significant		Decisive Alternative	Under	Non-Sig		Anecdotal Null

Table 54. *Summary of Non-First Letter Additive Factors Analyses (Associates Controlled and Uncontrolled)*

	IKSI				Log Proportion Correct			
	MIC	F	p	Bayes	MIC	F	p	Bayes
# of Meanings x # of Orth. NBRs	-5	4.6	.037	1.1	-.0117	3.8	.058	1.5
	Under	Significant		Anecdotal Null	Under	Non-Sig		Anecdotal Null
# of Meanings x KS Distance	-6	5.4	.024	1.3	-.0053	.956	.333	5.8
	Under	Significant		Anecdotal Alternative	Under	Non-Sig		Substantial Null
# of Meanings x Movement Type	12	19.5	<.001	346.2	.0155	6.5	.016	1.9
	Over	Significant		Decisive Alternative	Over	Significant		Anecdotal Alternative
# of Orth. NBRs x KS Distance	-7	7.2	.010	3.0	-.0083	2.4	.127	2.9
	Under	Significant		Anecdotal Alternative	Under	Non-Sig		Anecdotal Null
# of Orth. NBRs x Movement Type	11	13.0	<.001	31.7	.0335	29.2	<.001	9074.0
	Over	Significant		Very Strong Alternative	Over	Significant		Decisive Alternative

Table 55. *Effect Sizes for Non-First Keystroke Interaction Analyses*

		IKSI	Log Prop. Correct
# of Associates Controlled	# of Meanings x # of Orth. NBRs.	.209	.101
	# of Meanings x Row	.436	.003
	# of Orth. NBRs. x Row	.723	.163
# of Associates Controlled & Uncontrolled	# of Meanings x # of Orth. NBRs.	.496	.270
	# of Meanings x Row	.498	.244
	# of Orth. NBRs. x Row	.498	.451

The additive factors analyses indicated that number of meanings and number of orthographic neighbors had additive effects on IKSI when number of associates were controlled (MIC = -4; F=2.2, p=.140; Bayes = 3.2) and regardless of whether number of associates were controlled (MIC = -5; F=4.6, p=.037; Bayes = 1.1). The results also indicate that number of meanings and number of orthographic neighbors have additive effects on log proportions correct when number of associates are controlled (MIC = -.0053; F<1, p=.466; Bayes = 7.1) and regardless of whether number of associates are controlled (MIC = -.0117; F=3.8, p=.058; Bayes = 1.5). These findings are consistent with the results of the RT analyses and suggest that the two selection factors affect separate stages.

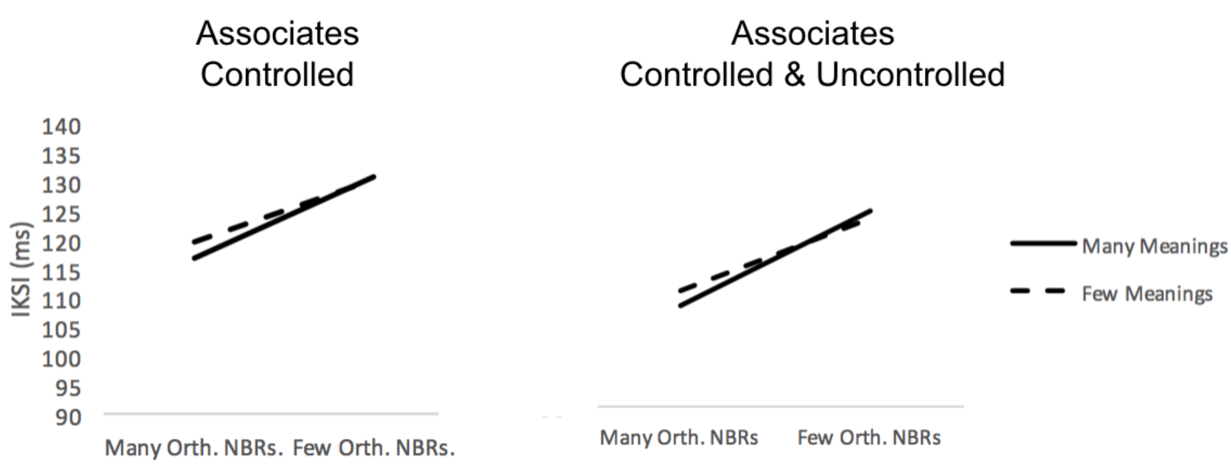

Figure 7. Effects of number of meanings and number of orthographic neighbors on IKSIs.

The additive factors analysis indicated substantial evidence that number of meanings and keystroke distance had additive effects on IKSI (MIC = -3; $F<1$, $p=.362$; Bayes = 6.1) and on log proportion correct (MIC = .0008; $F<1$, $p=.873$; Bayes = 9.1) when number of associates were controlled. There was anecdotal evidence that number of meanings and keystroke distance have under-additive effects on IKSI (MIC = -6; $F=5.4$, $p=.024$; Bayes = 1.3) and substantial evidence that the factors have additive effects on log proportion correct when collapsing over whether number of associates were controlled or not (MIC = -.0053; $F<1$, $p=.333$; Bayes = 5.8). It is unclear why number of meanings and keystroke distance would produce under-additive effects. Under-additive effects are produced in independent parallel exhausting structures. However, as previously discussed, such structures would be inappropriate for inner loop processes because the choice of which key to press should inform the execution of keystroke movements when producing intentional keystrokes. However, the Bayes factors suggest that the evidence is stronger for the additive effects on IKSI when number of associates are controlled than for the under-additive effects on IKSI when collapsing over whether number of associates are controlled or not.

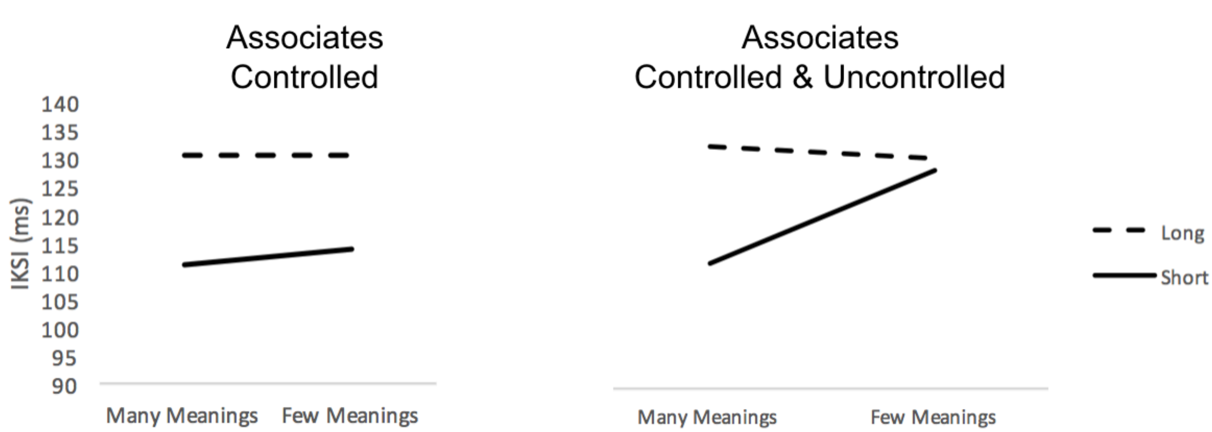

Figure 8. Effects of number of meanings and keystroke distance on IKSI.

The additive factors analysis indicated decisive evidence that number of meanings and movement type produce over-additive effects on IKSI when number of associates are controlled (MIC = 16; F=20.1, p<.001; Bayes = 445.3) and regardless of whether number of associates are controlled (MIC = 12; F=19.5, p<.001; Bayes = 346.2). These findings are consistent with the conclusion that number of meanings and movement type affect a common process. There is substantial evidence that number of meanings and movement type have additive effects on log proportion correct when number of associates are controlled (MIC = .0055; F<1, p=.925; Bayes = 9.1). Effect sizes were larger for the speed data than for the accuracy data (see Table 55), so the evidence for additive effects on log proportion correct may be attributable to low effect sizes. There is anecdotal evidence that the factors have under-additive effects on log proportion correct when collapsing over whether number of associates are controlled or not (MIC = .0155; F=6.5, p=.016; Bayes = 1.9). Again, it is unclear why number of meanings and movement type would produce under-additive effects but the evidence is anecdotal so it is possible that the result reflects a spurious effect.

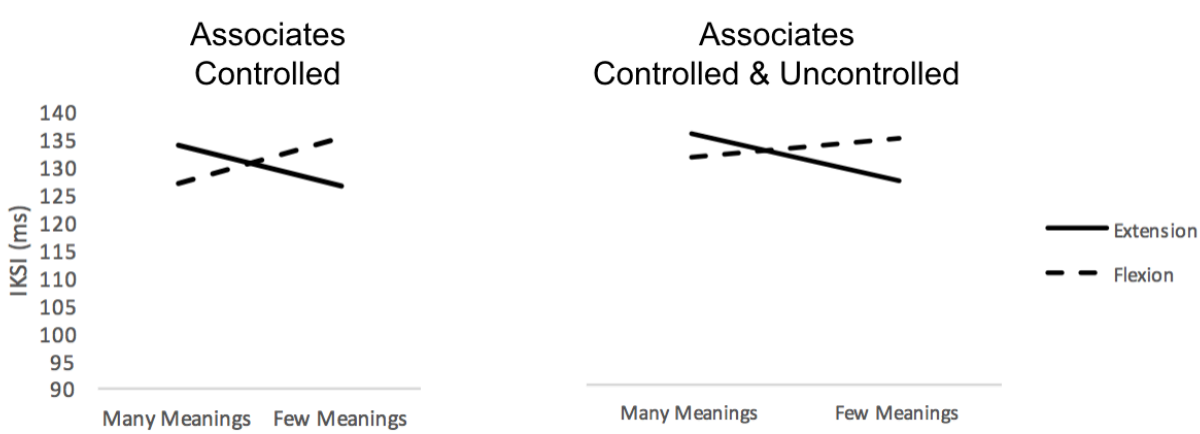

Figure 9. Effects of number of meanings and movement type on IKSI.

The additive factors analyses suggest that number of orthographic neighbors and keystroke distance have additive effects on IKSI (MIC = -4; F=2.0, p=.163; Bayes = 3.5) and on log proportion correct when number of associates controlled (MIC = .0008; F<1, p=.873; Bayes = 9.1). There is anecdotal evidence that number of orthographic neighbors and movement type have under-additive effects on IKSI (MIC = -7; F=7.2, p=.010; Bayes = 3.0) and additive effects on log proportions correct when collapsing over whether number of associates are controlled or not (MIC = -.0083; F=2.4, p=.127; Bayes = 2.9). The Bayes factors suggest that the evidence for additive effects is more convincing than the evidence for under-additivity, so it is likely the case that number of meanings and keystroke distance affect processes that are independent and serial.

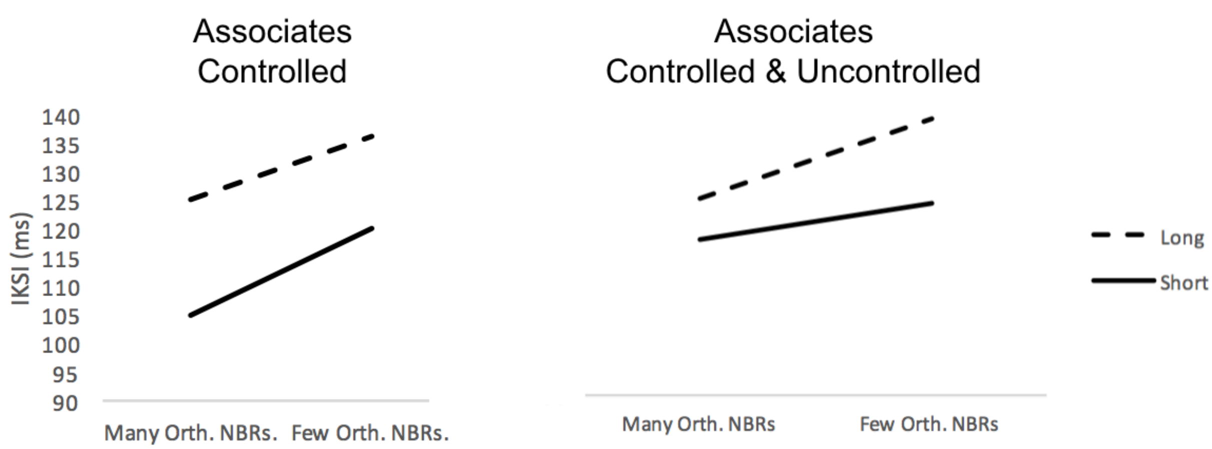

Figure 10. Effects of number of orthographic neighbors and keystroke distance on IKSI.

The additive factors analyses indicate that number of orthographic neighbors and movement type have over-additive effects on IKSI when number of associates are controlled (MIC = 25; F=49.0, p<.001; Bayes = 2,303,552) as well as on IKSI (MIC = 11; F=13.0, p<.001; Bayes = 31.7) and log proportion correct (MIC = .0335; F=29.2, p<.001; Bayes = 9,074.0) when collapsing over whether number of associates are controlled or not.

There is anecdotal evidence for additive effects on log proportion correct when number of associates are controlled (MIC = -.0125; F=2.5, p=.120; Bayes = 2.7). Effects sizes are larger for the speed data than for the accuracy data, so overall, these findings suggest that number of orthographic neighbors and movement type affect a common processing stage.

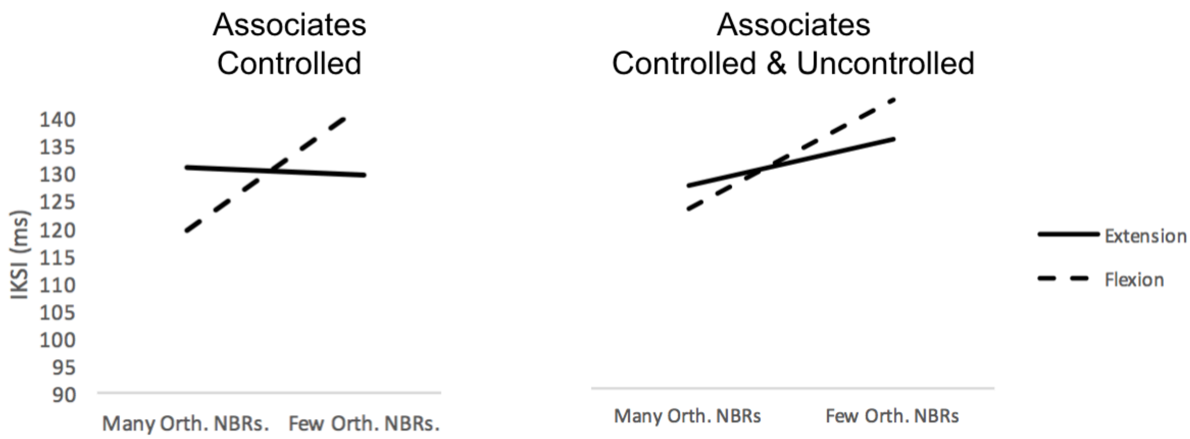

Figure 11. Effects of number of orthographic neighbors and movement type on IKSI.

Discussion. The processing structure suggested by analysis of non-first keystroke typing performance is depicted in Figure 12. The findings suggest that number of orthographic neighbors and number of meanings affect processes that are conducted by stages that are independent and serial. The movement type factor appears to affect the stage that processes number of orthographic neighbors and the stage that processes number of meanings. Keystroke distance appears to affect a stage of processing that is independent and serial of the other two stages.

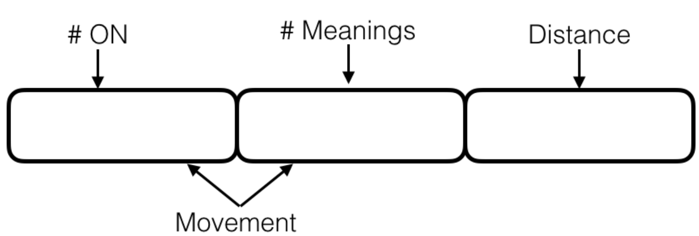

Figure 12. Processing structure suggested by analysis of non-first keystroke typing performance.

General Discussion

The purpose of the present study was to investigate the structure of the processes that underlie skilled typing performance, specifically those responsible for selecting which keys to type and for executing the requisite keystroke movements. According to Logan and Crump's (2011) two-loop model of skilled typing, an outer processing loop utilizes language generation or comprehension mechanisms to produce a series of words to type, which it sends one at a time to an inner processing loop that then produces the corresponding keystroke sequence. I proposed an elaboration of their theory which suggests the following (see Figure 13): In the case of transcription typing, the results of a visual analysis of presented text activate nodes in an orthographic representational layer, which transmit activity to nodes in a semantic representational layer, which transmit activity to a layer of pointer nodes, which transmit activity to key representational nodes. When the activity of a node in the key representational layer reaches its threshold level, the corresponding keystroke movement is initiated and results in the pressing of a key. Therefore, the input to Logan and Crump's outer processing loop is the visual information provided by the to-be-transcribed text. The output of the outer loop are active pointer representations. The input to the inner loop are active pointer representations. The output of the inner loop are pressed keys. I termed this elaboration the two-step model of inner loop processing because I suggested that the inner loop is comprised of two processing stages, a key selection stage and a keystroke execution stage, that are independent and serial. The input to the key selection stage are active pointer representations. The output of the key selection stage is a chosen key representation. The chosen key representation is then input into the keystroke execution stage, which outputs a keystroke movement. I also noted an alternative possibility, that top-down key selection information and bottom-up keystroke execution information are input into a common inner loop stage where they are processed co-actively and jointly contribute to the production of directed keystrokes.

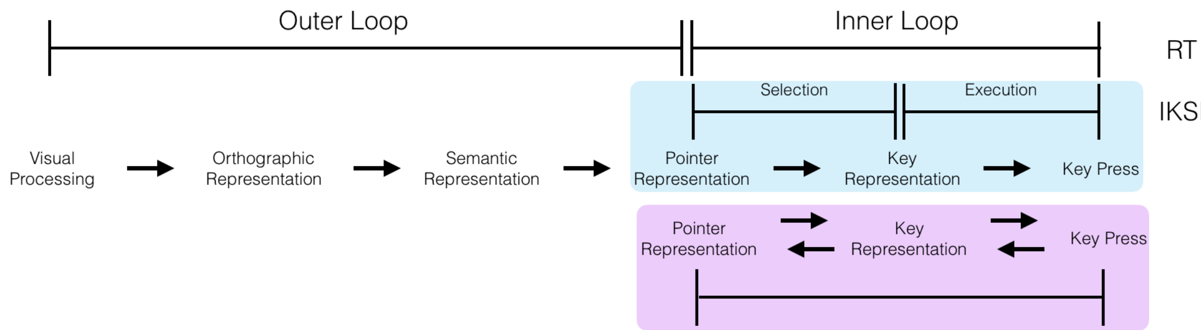

Figure 13. Depiction of how the proposed information processing sequence maps onto Logan and Crump's (2011) two-loop theory of skilled typing. The shaded areas depict the two-stage (Blue) and one-stage (Purple) structures proposed a priori.

I assessed the effects of two selection factors (i.e., number of orthographic neighbors and number of meanings) and two execution factors (i.e., movement type and keystroke distance) on typing performance. I suggested that the two selection factors should influence the strength of the evidence for the correct key representation option and, as such, the rate at which it accrues activity. The two execution factors were expected to affect the duration of keystroke movements. Therefore, if key selection and keystroke execution are processed independently by serial stages, the effects of factors that selectively influence either key selection or keystroke execution would be additive on typing performance. However, if key selection and keystroke execution are processed within a common stage, factor effects would interact in an over-additive manner on typing performance.

I assessed the effects of the factors on the performance of first-letter keystrokes and non-first letter keystrokes of transcribed words. Analysis of first keystroke performance indicated the following: First, number of orthographic neighbors, number of meanings, and row all had significant main effects. Second, the effects of number of orthographic neighbors and number of meanings were additive. Third, the effects of number of orthographic neighbors and movement type as well as the effects of number of orthographic neighbors and keystroke distance were additive. Fourth, the effects of number of meanings and movement type as well as the effects of number of meanings and keystroke distance were over-additive. These findings suggest that number of orthographic neighbors affect one stage, that number of meanings, movement type, and keystroke distance affect another stage, and that these two stages are independent and serial (see Figure 14).

Recall that first keystroke performance is determined by both outer and inner loop processes. Therefore, the results of the first keystroke analyses may be reflecting the outer and inner loops as two processing stages. In the information processing sequence I originally proposed (see Figure 13), I suggested that active pointer representations are output from the outer loop and input into the inner loop. However, if the results of the first keystroke analyses are reflecting outer and inner loop processing, it would mean that the point at which information is transmitted from the outer loop to the inner loop occurs after orthographic representations are activated and before semantic representations are activated.

Alternatively, the results of the first keystroke analyses may be reflecting a distinction between perceptual and cognitive processing. That is, there may be a stage that is responsible for processing visually presented text and activating orthographic representations that is independent and serial of all of the processes that follow. If so, it would not necessarily imply that all of the following processes are conducted within a common stage. In the case of transcription typing, the outer loop is responsible for both perceiving visual information and identifying to-be-typed words. Such processes likely have longer and more variable durations than inner loop processes. Therefore, it is possible that factor effects on inner loop processes were washed out in the first keystroke data.

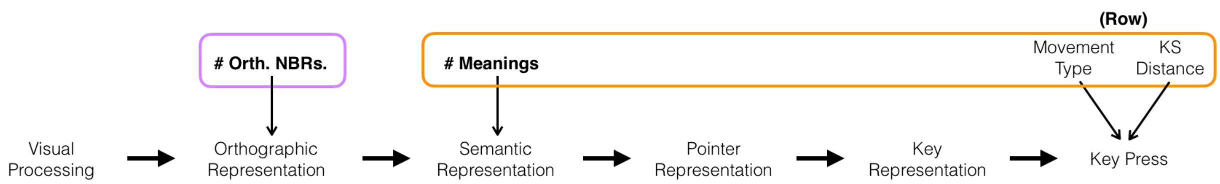

Figure 14. Relationship between the results of the first keystroke analyses and the proposed information processing sequence.

Analyses of non-first letter keystrokes indicated the following (see Figure 15): First, number of orthographic neighbors and row had significant main effects but number of meanings did not. Second, the effects of number of orthographic neighbors and number of meanings were additive. Third, the effects of number of meanings and movement type as well as the effects of number of orthographic neighbors and movement type were over-additive. Fourth, the effects of keystroke distance and each of the other three factors were additive.

Recall that non-first letter keystrokes depend on inner loop processes. Therefore, the fact that number of meanings had a significant main effect on first letter keystrokes but not on non-first letter keystrokes suggests that semantic processing occurs in the outer loop, which is consistent with Logan and Crump's (2011) characterization of outer loop processing. I previously suggested that, in the case of transcription typing, orthographic processing would need to precede semantic processing. In fact, the results of the first letter keystroke analyses are consistent with that suggestion. However, the fact that number of orthographic neighbors had a significant main effect on non-first letter keystrokes suggests that orthographic information also affects inner loop processes. Therefore, it appears that orthographic information affects transcription typing processes once when perceiving the presented text and once by affecting the amount of activity that is transmitted to pointer or key representations.

The movement type factor was expected to reflect differences in the physical difficulties of extending versus flexing fingers. However, the fact that movement type but not keystroke distance interacted over-additively with both of the selection factors suggest that movement type is either a non-selective factor (i.e., a factor that affects the processing conducted by more than one stage) or a selection factor. Finger extensions are required for keys that are located above the home row and finger flexions are required for keys that are located below the home row. Therefore, the kind of movement required is co-incident with the location/direction of a given key. As a result, it is possible that the movement type factor tapped in to the key location or keystroke direction information that may be encoded in pointer or key representations. If these representations are linked via associations, activity could spread out laterally to representations that encode similar location or direction information, which would affect the strength of the evidence for the correct option. Unfortunately, because movement type and keystroke distance were orthogonal in the current study, there is no information about whether they affect a common stage. However, the fact that the effects of keystroke distance and the two selection factors were additive suggests that keystroke distance affects a stage that is independent and serial of the stage(s) affected by the selection factors.

Even though number of meanings did not have a significant main effect on non-first letter keystrokes, it did interact with movement type. This suggests that while number of meanings may mostly play a role in identifying to-be-typed words, it also affects the amount of activity that is transmitted to pointer and key representations. Number of orthographic neighbors had a significant main effect on non-first letter keystrokes, interacted with movement type, but was additive with number of meanings. These findings suggest that number of meanings, number of orthographic neighbors, and movement type all affect key selection but that the effect of number of meanings occurs before the effect of number of orthographic neighbors.

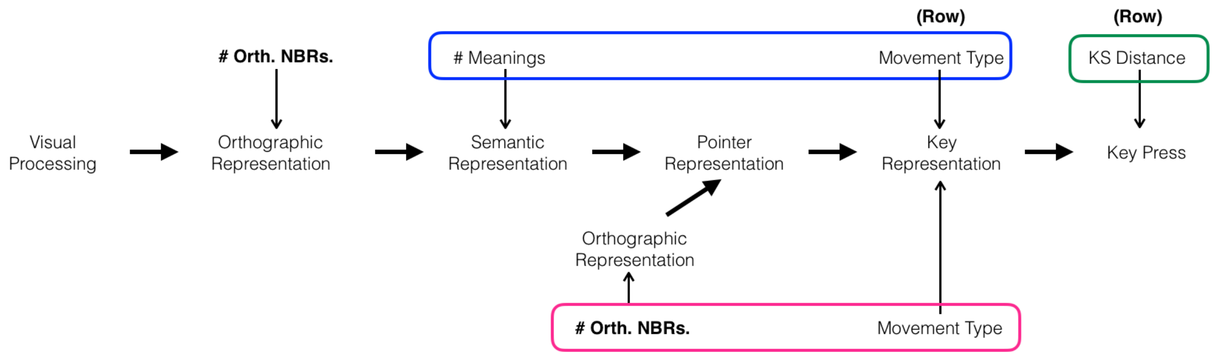

Figure 15. Relationship between the results of the non-first letter first keystroke analyses and the proposed information processing sequence.

In sum, the results of the study are consistent with the conclusion that skilled typing is controlled by at least four independent, serial processing stages (see Figure 16). The outer loop appears to be comprised of a perception stage and a word identification stage. The inner loop appears to be comprised of a key selection and a keystroke execution stage.

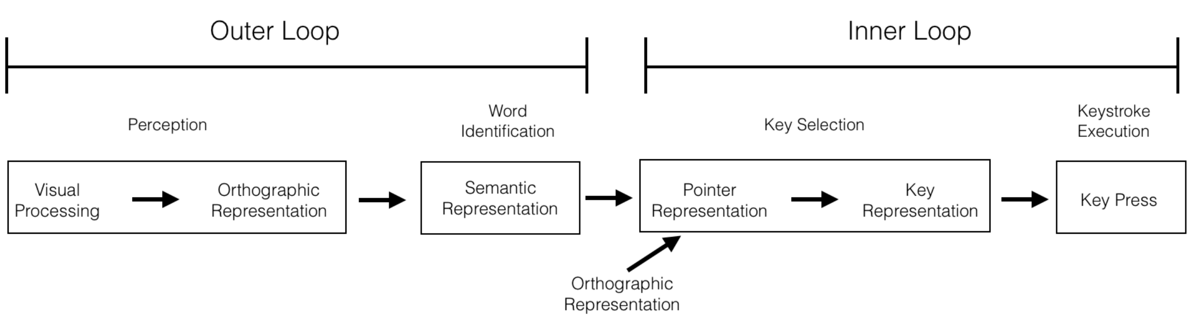

Figure 16. Processing structure implied by study findings.

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Appendix A: Factor Effect Predictions

For each case the equation being solved is SS – SF – FS + FF = MIC, where S = Slow factor level and F = Fast factor level.
T = Threshold, C = Weight of Correct Option, A = Summed Weights of Alternatives,
N = Factor, L = Factor. Unless otherwise specified, T, C, A, N, and L are ≥ 1.
Solutions = 0 are additive. Solutions > 1 are over-additive. Solutions < 1 are under-additive.

1. One variable affects the numerator of Luce, One variable affects the denominator of Luce

SS	SF	FS	FF	Solution
$\frac{T(C+A+L)}{C}$	$\frac{T(C+A)}{C}$	$\frac{T(C+N+A+L)}{C+N}$	$\frac{T(C+N+A)}{C+N}$	$\frac{LNT}{C^2+CN}$

*Solution is positive

2. Both Variables affect the numerator of Luce

SS	SF	FS	FF	Solution
$\frac{T(C+A)}{C}$	$\frac{T(C+N+A)}{C+N}$	$\frac{T(C+A+L)}{C+L}$	$\frac{T(C+N+A+L)}{C+N+L}$	$\frac{ALNT(2C+N+L)}{C(C+N)(C+L)(C+N+L)}$

*Solution is positive

3. Both variables affect the denominator of Luce

SS	SF	FS	FF	Solution
$\frac{T(C+A+N+L)}{C}$	$\frac{T(C+N+A)}{C}$	$\frac{T(C+A+L)}{C}$	$\frac{T(C+A)}{C}$	0

*Solution is additive

4. One variable affects threshold via additive increase. One variable affects the denominator of Luce.

SS	SF	FS	FF	Solution
$\frac{(T+N)(C+A+L)}{C}$	$\frac{(T+N)(C+A)}{C}$	$\frac{T(C+A+L)}{C}$	$\frac{T(C+A)}{C}$	$\frac{LN}{C}$

*Solution is positive

5. One variable affects threshold via additive decrease. One variable affects the denominator of Luce.

SS	SF	FS	FF	Solution
$\frac{T(C+A+L)}{C}$	$\frac{T(C+A)}{C}$	$\frac{(T-N)(C+A+L)}{C}$	$\frac{(T-N)(C+A)}{C}$	$\frac{LN}{C}$

*Solution is positive

6. One variable affects threshold via multiplicative increase. One variable affects the denominator of Luce.

SS	SF	FS	FF	Solution
$\frac{TN(C+A+L)}{C}$	$\frac{TN(C+A)}{C}$	$\frac{T(C+A+L)}{C}$	$\frac{T(C+A)}{C}$	$\frac{LT(N-1)}{C}$

* $N \geq 1$, Solution is positive

7. One variable affects threshold via multiplicative decrease. One variable affects the denominator of Luce.

SS	SF	FS	FF	Solution
$\frac{T(C+A+L)}{C}$	$\frac{T(C+A)}{C}$	$\frac{TN(C+A+L)}{C}$	$\frac{TN(C+A)}{C}$	$\frac{LT(1-N)}{C}$

* $N < 1$, Solution is positive

8. One variable affects threshold via additive increase. One variable affects the numerator of Luce.

SS	SF	FS	FF	Solution
$\frac{(T+N)(C+A)}{C}$	$\frac{(T+N)(C+A+L)}{C+L}$	$\frac{T(C+A)}{C}$	$\frac{T(C+A+L)}{C+L}$	$\frac{ALN}{C^2+CL}$

*Solution is positive

9. One variable affects threshold via additive decrease. One variable affects the numerator of Luce.

SS	SF	FS	FF	Solution
$\frac{T(C+A)}{C}$	$\frac{T(C+A+L)}{C+L}$	$\frac{(T-N)(C+A)}{C}$	$\frac{(T-N)(C+A+L)}{C+L}$	$\frac{ALN}{C^2+CL}$

*Solution is positive

10. One variable affects threshold via multiplicative increase. One variable affects the numerator of Luce.

SS	SF	FS	FF	Solution
$\frac{TN(C+A)}{C}$	$\frac{TN(C+A+L)}{C+L}$	$\frac{T(C+A)}{C}$	$\frac{T(C+A+L)}{C+L}$	$\frac{ALT(N-1)}{C^2+CL}$

* $N \geq 1$, Solution is positive

11. One variable affects threshold via multiplicative decrease. One variable affects the numerator of Luce.

SS	SF	FS	FF	Solution
$\frac{T(C+A)}{C}$	$\frac{T(C+A+L)}{C+L}$	$\frac{TN(C+A)}{C}$	$\frac{TN(C+A+L)}{C+L}$	$\frac{ALT(1-N)}{C^2+CL}$

* $N < 1$, Solution is positive

12. Both variables affect threshold via additive increase.

SS	SF	FS	FF	Solution
$\frac{(T+N+L)(C+A)}{C}$	$\frac{(T+N)(C+A)}{C}$	$\frac{(T+L)(C+A)}{C}$	$\frac{T(C+A)}{C}$	0

*Solution is additive

13. Both variables affect threshold via additive decrease.

SS	SF	FS	FF	Solution
$\frac{T(C+A)}{C}$	$\frac{(T-N)(C+A)}{C}$	$\frac{(T-L)(C+A)}{C}$	$\frac{(T-N-L)(C+A)}{C}$	0

*Solution is additive

14. Both variables affect threshold via multiplicative increase.

SS	SF	FS	FF	Solution
$\frac{TNL(C+A)}{C}$	$\frac{TL(C+A)}{C}$	$\frac{TN(C+A)}{C}$	$\frac{T(C+A)}{C}$	$\frac{(AT+CT)(LN+1-L-N)}{C}$

* L & $N \geq 1$, Solution is positive

15. Both variables affect threshold via multiplicative decrease.

SS	SF	FS	FF	Solution
$\frac{T(C+A)}{C}$	$\frac{TL(C+A)}{C}$	$\frac{TN(C+A)}{C}$	$\frac{TNL(C+A)}{C}$	$\frac{(AT+CT)(LN+1-L-N)}{C}$

* L & $N < 1$, Solution is positive

Appendix B: Stimuli Characteristics for the First Keystroke Analyses

Column 2: Number of associates controlled (C) or uncontrolled (U). Column 3: Many (M) many or few (F) number of meanings. Column 4: Many (M) or few (F) number of orthographic neighbors. Column 4: First keystroke is a top (T), home (H), or bottom (B) row key. Column 5 and 6: Word's number of definitions and senses, respectively, as indicated in the Wordsmyth database. Column 10: Frequency of first letter.

Word	Assoc. Control	Meanings	Orth. NBRs.	Row	Defs.	Senses	# of Orth. NBRs.	# of Assocs.	Word Freq.	Letter Freq.
BANJO	C	F	F	B	1	1	0.0	14	1.7	1.5
BISON	C	F	F	B	1	2	0.0	10	2.2	1.5
BUYER	C	F	F	B	1	2	1.0	8	5.9	1.5
CABIN	C	F	F	B	1	2	1.0	9	21.6	3.3
CHAOS	C	F	F	B	1	2	2.0	22	15.2	3.3
CIGAR	C	F	F	B	1	1	0.5	7	10.1	3.3
CLIFF	C	F	F	B	1	1	0.5	12	15.5	3.3
CLOAK	C	F	F	B	1	2	2.0	11	3.7	3.3
MAYOR	C	F	F	B	1	1	2.5	20	38.2	2.5
MESSY	C	F	F	B	1	2	2.0	17	5.3	2.5
MONKS	C	F	F	B	1	1	2.0	8	6.1	2.5
NAIVE	C	F	F	B	1	2	2.0	15	7.4	7.2
NERVY	C	F	F	B	1	2	1.5	24	0.3	7.2
NIECE	C	F	F	B	1	1	2.0	9	7.5	7.2
NOISY	C	F	F	B	1	2	1.5	8	6.2	7.2
NOTED	C	F	F	B	1	1	2.5	16	54.8	7.2
VALOR	C	F	F	B	1	1	1.0	15	1.2	1.1
VERBS	C	F	F	B	1	1	1.5	10	3.2	1.1
VIOLA	C	F	F	B	1	1	1.5	15	5.6	1.1
VODKA	C	F	F	B	1	1	0.0	17	7.8	1.1
CADET	U	F	F	B	1	1	1.0	N	3.2	3.3
CAMEL	U	F	F	B	1	1	2.5	11	3.6	3.3
CANAL	U	F	F	B	1	2	2.0	18	6.2	3.3
CANOE	U	F	F	B	1	1	2.0	8	5.6	3.3
CARGO	U	F	F	B	1	1	2.0	N	9.5	3.3
CHALK	U	F	F	B	1	2	0.0	7	3.7	3.3
CHOIR	U	F	F	B	1	2	1.5	10	7.8	3.3
CIDER	U	F	F	B	1	1	2.5	N	2.7	3.3
CIVIC	U	F	F	B	1	2	1.5	N	14.6	3.3
CLODS	U	F	F	B	1	2	2.0	N	3.2	3.3
COMBO	U	F	F	B	1	2	1.5	N	3.0	3.3
CREDO	U	F	F	B	1	2	0.5	N	3.3	3.3

MOTOR	U	F	F	B	1	1	2.0	N	30.8	2.5
NASAL	U	F	F	B	1	2	1.5	N	3.8	7.2
NAVAL	U	F	F	B	1	2	2.5	N	17.3	7.2
NEWTS	U	F	F	B	1	1	2.5	N	2.0	7.2
NIFTY	U	F	F	B	1	1	1.0	N	1.5	7.2
NINTH	U	F	F	B	1	1	0.0	N	13.2	7.2
NOMAD	U	F	F	B	1	2	0.0	18	0.7	7.2
NOUNS	U	F	F	B	1	1	1.5	7	3.0	7.2
ACRES	C	F	F	H	1	2	2.5	9	26.9	8.0
AMAZE	C	F	F	H	1	1	0.5	16	1.8	8.0
APART	C	F	F	H	1	2	0.5	8	54.8	8.0
AVOID	C	F	F	H	1	2	1.5	17	54.0	8.0
DICEY	C	F	F	H	1	1	1.5	23	0.8	3.8
DRYLY	C	F	F	H	1	1	0.5	18	2.8	3.8
FRISK	C	F	F	H	1	1	2.5	12	0.9	2.4
FUNGI	C	F	F	H	1	1	0.0	14	3.8	2.4
GAUZE	C	F	F	H	1	2	2.0	13	1.5	1.9
GEESE	C	F	F	H	1	1	1.0	13	3.0	1.9
GIFTS	C	F	F	H	1	2	1.5	16	16.5	1.9
GRAVY	C	F	F	H	1	2	1.5	13	4.6	1.9
GULPS	C	F	F	H	1	1	1.0	12	2.3	1.9
JAZZY	C	F	F	H	1	2	0.5	14	0.8	0.2
KNEEL	C	F	F	H	1	1	2.0	13	4.2	0.5
SALAD	C	F	F	H	1	2	0.5	15	17.8	6.5
SATIN	C	F	F	H	1	1	2.0	9	4.0	6.5
SOFAS	C	F	F	H	1	1	1.0	10	3.2	6.5
SONIC	C	F	F	H	1	2	2.0	17	2.2	6.5
STEWS	C	F	F	H	1	1	2.5	10	2.4	6.5
DEALT	U	F	F	H	1	1	1.5	N	15.7	3.8
DELTA	U	F	F	H	1	2	0.5	N	7.0	3.8
DOGMA	U	F	F	H	1	2	0.0	N	3.2	3.8
DONOR	U	F	F	H	1	2	2.0	10	6.0	3.8
FIFTH	U	F	F	H	1	1	2.0	N	31.9	2.4
FLOUR	U	F	F	H	1	2	2.0	13	11.7	2.4
FOAMY	U	F	F	H	1	2	1.0	19	1.9	2.4
FOCAL	U	F	F	H	1	1	2.5	N	5.2	2.4
FOLKS	U	F	F	H	1	2	2.5	N	49.8	2.4
FOYER	U	F	F	H	1	2	2.5	N	2.7	2.4
FROZE	U	F	F	H	1	1	0.5	N	5.1	2.4

FUMES	U	F	F	H	1	2	1.5	16	3.9	2.4
GENIE	U	F	F	H	1	1	1.5	N	1.9	1.9
GENRE	U	F	F	H	1	2	2.0	N	4.9	1.9
GUARD	U	F	F	H	1	2	0.5	18	58.6	1.9
LATEX	U	F	F	H	1	2	1.5	N	2.1	4.1
LEAPT	U	F	F	H	1	1	2.5	11	2.3	4.1
LIARS	U	F	F	H	1	1	1.0	18	2.1	4.1
LOGOS	U	F	F	H	1	1	2.0	N	3.1	4.1
LUNGS	U	F	F	H	1	1	2.5	11	14.4	4.1
OVALS	C	F	F	T	1	1	0.5	10	2.6	7.6
OWNED	C	F	F	T	1	2	2.0	16	28.2	7.6
OZONE	C	F	F	T	1	1	0.5	17	5.2	7.6
PATIO	C	F	F	T	1	2	1.0	18	3.9	2.1
PAUSE	C	F	F	T	1	2	2.0	14	16.5	2.1
PHONY	C	F	F	T	1	1	2.0	14	8.5	2.1
PHOTO	C	F	F	T	1	1	1.0	15	22.7	2.1
POEMS	C	F	F	T	1	2	1.5	28	33.6	2.1
PORKY	C	F	F	T	1	2	2.5	10	0.4	2.1
QUEST	C	F	F	T	1	1	1.5	16	13.2	0.1
ROBOT	C	F	F	T	1	2	1.0	15	7.7	6.3
RODEO	C	F	F	T	1	1	1.5	8	3.6	6.3
RURAL	C	F	F	T	1	2	1.5	16	34.5	6.3
TABOO	C	F	F	T	1	1	0.0	24	2.6	9.3
TULIP	C	F	F	T	1	2	0.5	7	2.2	9.3
ULCER	C	F	F	T	1	2	0.5	14	3.1	2.7
USURP	C	F	F	T	1	1	0.5	4	0.8	2.7
WAXEN	C	F	F	T	1	2	2.0	13	0.6	1.7
WEIRD	C	F	F	T	1	2	1.5	15	43.8	1.7
WIDOW	C	F	F	T	1	1	1.0	13	16.4	1.7
PERIL	U	F	F	T	1	2	0.0	N	4.7	2.1
PIZZA	U	F	F	T	1	1	1.0	14	18.0	2.1
POSSE	U	F	F	T	1	2	2.0	N	5.7	2.1
RADAR	U	F	F	T	1	2	0.0	N	23.8	6.3
RAINY	U	F	F	T	1	1	2.0	11	5.0	6.3
RANCH	U	F	F	T	1	2	1.0	12	20.3	6.3
RATIO	U	F	F	T	1	2	2.5	N	20.0	6.3
REALM	U	F	F	T	1	2	1.5	N	13.1	6.3
REFER	U	F	F	T	1	2	2.5	N	18.0	6.3
RINSE	U	F	F	T	1	2	0.5	10	4.6	6.3

RISKY	U	F	F	T	1	1	2.0	13	8.0	6.3
RIVAL	U	F	F	T	1	2	0.5	N	11.1	6.3
ROBIN	U	F	F	T	1	2	1.5	6	12.0	6.3
RUMOR	U	F	F	T	1	1	2.5	16	8.6	6.3
UPPER	U	F	F	T	1	2	2.0	5	43.9	2.7
URINE	U	F	F	T	1	1	0.5	N	4.8	2.7
WHEAT	U	F	F	T	1	2	2.0	17	9.9	1.7
WITTY	U	F	F	T	1	2	2.5	12	5.6	1.7
YACHT	U	F	F	T	1	1	0.5	11	5.7	1.7
YIELD	U	F	F	T	1	2	2.5	14	20.5	1.7
CANDY	C	F	M	B	1	1	6.5	14	24.3	3.3
CAVED	C	F	M	B	1	2	8.5	11	1.1	3.3
CAVES	C	F	M	B	1	2	11.5	11	5.3	3.3
CENTS	C	F	M	B	1	2	5.0	12	24.3	3.3
CHOPS	C	F	M	B	1	1	6.0	15	4.4	3.3
CHORE	C	F	M	B	1	2	6.0	17	3.6	3.3
CHUNK	C	F	M	B	1	2	5.0	19	4.5	3.3
CLAMP	C	F	M	B	1	2	7.5	21	4.7	3.3
COALS	C	F	M	B	1	2	5.0	14	3.9	3.3
COAST	C	F	M	B	1	2	5.0	22	43.2	3.3
COINS	C	F	M	B	1	2	6.5	12	6.9	3.3
COLTS	C	F	M	B	1	2	7.5	9	3.1	3.3
COMET	C	F	M	B	1	1	4.5	14	4.9	3.3
COUCH	C	F	M	B	1	1	7.0	12	19.3	3.3
COUGH	C	F	M	B	1	2	5.5	11	7.6	3.3
CRAVE	C	F	M	B	1	2	7.0	11	2.2	3.3
CRIED	C	F	M	B	1	1	5.5	14	23.2	3.3
CROAK	C	F	M	B	1	2	4.5	6	1.0	3.3
NAILS	C	F	M	B	1	2	10.0	11	12.6	7.2
NINES	C	F	M	B	1	2	7.5	9	0.8	7.2
CAFES	U	F	M	B	1	1	7.5	N	4.2	3.3
CEASE	U	F	M	B	1	1	5.5	N	9.9	3.3
CHOSE	U	F	M	B	1	1	7.5	N	31.8	3.3
CLONE	U	F	M	B	1	2	6.0	N	3.2	3.3
CLUNG	U	F	M	B	1	1	5.5	N	6.5	3.3
CRAPS	U	F	M	B	1	1	10.5	N	1.9	3.3
CRATE	U	F	M	B	1	2	8.0	N	3.2	3.3
CREED	U	F	M	B	1	2	6.5	N	4.3	3.3

CURLY	U	F	M	B	1	1	4.5	N	5.4	3.3
MAKER	U	F	M	B	1	2	6.5	17	11.5	2.5
MERGE	U	F	M	B	1	2	5.5	N	5.2	2.5
METAL	U	F	M	B	1	2	4.5	16	44.8	2.5
MINER	U	F	M	B	1	1	10.5	15	1.9	2.5
MINUS	U	F	M	B	1	2	6.0	10	7.6	2.5
MOOSE	U	F	M	B	1	1	7.0	18	5.9	2.5
NANNY	U	F	M	B	1	1	5.0	N	7.3	7.2
NATTY	U	F	M	B	1	1	6.5	N	0.7	7.2
NAVEL	U	F	M	B	1	2	5.0	N	1.7	7.2
NODES	U	F	M	B	1	2	5.5	N	2.0	7.2
NOOKS	U	F	M	B	1	1	6.0	N	2.3	7.2
AIDED	C	F	M	H	1	2	5.5	7	5.5	8.0
DINED	C	F	M	H	1	2	7.0	6	1.8	3.8
DITCH	C	F	M	H	1	2	7.0	14	8.2	3.8
DRAWN	C	F	M	H	1	1	6.5	15	42.3	3.8
FAKER	C	F	M	H	1	1	5.5	19	0.9	2.4
GIVER	C	F	M	H	1	1	6.0	13	1.1	1.9
GUMMY	C	F	M	H	1	2	4.5	9	0.7	1.9
JAILS	C	F	M	H	1	2	9.5	15	2.2	0.2
LAKES	C	F	M	H	1	1	11.0	15	7.4	4.1
LASER	C	F	M	H	1	1	5.5	13	12.1	4.1
LINEN	C	F	M	H	1	2	5.5	11	5.4	4.1
LUCKS	C	F	M	H	1	2	9.0	16	2.0	4.1
SCARE	C	F	M	H	1	1	11.5	11	15.8	6.5
SHONE	C	F	M	H	1	1	7.0	9	3.7	6.5
SLUMS	C	F	M	H	1	1	5.0	20	3.7	6.5
SNORE	C	F	M	H	1	1	7.5	11	1.3	6.5
STABS	C	F	M	H	1	2	5.5	12	0.9	6.5
STUCK	C	F	M	H	1	1	6.5	18	43.8	6.5
SUITE	C	F	M	H	1	2	6.5	13	18.1	6.5
SWAMP	C	F	M	H	1	1	4.5	24	7.0	6.5
ANGER	U	F	M	H	1	1	5.0	14	37.2	8.0
DRIED	U	F	M	H	1	1	5.5	18	19.2	3.8
FILLY	U	F	M	H	1	2	10.0	N	3.6	2.4
FLEES	U	F	M	H	1	1	6.5	11	0.7	2.4
FORKS	U	F	M	H	1	2	6.5	8	4.3	2.4
GLADE	U	F	M	H	1	1	7.0	N	0.7	1.9
GUNNY	U	F	M	H	1	2	4.5	N	2.3	1.9

HICKS	U	F	M	H	1	1	6.5	N	3.2	5.1
HILLY	U	F	M	H	1	1	8.5	14	1.4	5.1
JOLLY	U	F	M	H	1	2	8.0	N	4.7	0.2
KINGS	U	F	M	H	1	1	5.5	8	8.0	0.5
LACES	U	F	M	H	1	1	9.5	24	1.2	4.1
SAINT	U	F	M	H	1	2	4.5	24	14.5	6.5
SHAVE	U	F	M	H	1	1	11.5	12	8.1	6.5
SHIRT	U	F	M	H	1	1	5.5	17	39.3	6.5
SPITE	U	F	M	H	1	2	8.0	N	27.1	6.5
SPORE	U	F	M	H	1	1	10.0	N	0.7	6.5
STARE	U	F	M	H	1	1	15.0	12	14.0	6.5
STUNG	U	F	M	H	1	1	6.5	N	2.4	6.5
SWANK	U	F	M	H	1	2	5.0	N	1.0	6.5
PAILS	C	F	M	T	1	2	12.5	7	3.2	2.1
PANES	C	F	M	T	1	2	12.0	3	3.2	2.1
PILES	C	F	M	T	1	2	11.0	20	4.2	2.1
PIPER	C	F	M	T	1	1	5.5	15	16.0	2.1
PLOWS	C	F	M	T	1	2	5.5	17	1.5	2.1
PORCH	C	F	M	T	1	2	5.0	15	26.3	2.1
PROSE	C	F	M	T	1	1	5.5	15	7.2	2.1
PUSHY	C	F	M	T	1	1	4.5	21	1.7	2.1
QUILT	C	F	M	T	1	2	6.5	16	3.6	0.1
RISER	C	F	M	T	1	2	6.5	10	0.5	6.3
ROADS	C	F	M	T	1	2	5.5	24	32.7	6.3
ROPES	C	F	M	T	1	2	9.0	21	5.5	6.3
TAPES	C	F	M	T	1	2	8.5	18	11.0	9.3
TASKS	C	F	M	T	1	2	5.5	11	19.6	9.3
TOWEL	C	F	M	T	1	1	5.0	19	11.1	9.3
TRAYS	C	F	M	T	1	2	3.5	19	2.7	9.3
TUNER	C	F	M	T	1	2	4.5	14	0.8	9.3
TYING	C	F	M	T	1	1	5.5	17	4.8	9.3
WAGES	C	F	M	T	1	2	11.0	10	21.1	1.7
WIVES	C	F	M	T	1	1	9.5	8	18.5	1.7
PASSE	U	F	M	T	1	2	5.0	N	2.9	2.1
PATTY	U	F	M	T	1	2	10.5	N	6.8	2.1
PAVED	U	F	M	T	1	1	5.0	N	4.0	2.1
PEARS	U	F	M	T	1	2	15.0	9	2.3	2.1
PIERS	U	F	M	T	1	2	3.5	N	4.2	2.1
PILLS	U	F	M	T	1	2	11.0	14	15.2	2.1
PLUSH	U	F	M	T	1	1	4.5	23	2.3	2.1

POETS	U	F	M	T	1	2	4.5	17	14.4	2.1
PRANK	U	F	M	T	1	1	5.0	17	2.1	2.1
PROBE	U	F	M	T	1	2	4.5	N	7.6	2.1
PRONE	U	F	M	T	1	2	7.5	N	8.2	2.1
QUINT	U	F	M	T	1	1	4.5	N	4.1	0.1
REINS	U	F	M	T	1	2	4.5	N	4.7	6.3
RIDER	U	F	M	T	1	2	7.0	12	10.9	6.3
RITES	U	F	M	T	1	2	7.5	N	3.2	6.3
ROLES	U	F	M	T	1	2	9.5	N	24.7	6.3
ROVER	U	F	M	T	1	2	10.0	N	4.2	6.3
TEAMS	U	F	M	T	1	2	7.0	17	37.7	9.3
WAGED	U	F	M	T	1	2	9.5	10	3.7	1.7
WAVES	U	F	M	T	1	1	10.0	8	33.2	1.7
BUGLE	C	M	F	B	3	3	0.5	13	1.5	1.5
CHEAP	C	M	F	B	1	7	2.5	13	30.4	3.3
CHESS	C	M	F	B	3	3	2.5	14	5.9	3.3
CLIMB	C	M	F	B	1	4	1.5	15	19.0	3.3
CLUBS	C	M	F	B	1	6	2.0	22	19.4	3.3
CODED	C	M	F	B	1	4	2.5	20	2.9	3.3
CRISP	C	M	F	B	1	4	1.5	23	8.2	3.3
CRUDE	C	M	F	B	1	6	2.0	13	10.3	3.3
CUBED	C	M	F	B	1	5	2.5	11	2.3	3.3
CUFFS	C	M	F	B	2	6	2.0	12	3.5	3.3
CYCLE	C	M	F	B	1	5	0.5	17	20.4	3.3
MAGIC	C	M	F	B	1	4	1.5	23	43.8	2.5
MASON	C	M	F	B	1	3	1.0	20	13.4	2.5
MERIT	C	M	F	B	1	4	0.5	15	14.4	2.5
MINOR	C	M	F	B	1	4	2.5	13	35.0	2.5
MOIST	C	M	F	B	1	4	2.5	5	6.9	2.5
MUTED	C	M	F	B	1	5	2.0	10	2.7	2.5
MYTHS	C	M	F	B	1	4	1.5	19	5.1	2.5
NERVE	C	M	F	B	1	5	2.5	24	17.4	7.2
NICER	C	M	F	B	1	6	1.0	14	4.1	7.2
BATON	U	M	F	B	1	4	2.5	N	6.2	1.5
BLEAK	U	M	F	B	2	3	2.5	N	5.7	1.5
BOSOM	U	M	F	B	1	4	1.0	N	4.5	1.5
BROIL	U	M	F	B	2	3	0.5	N	1.8	1.5
CHORD	U	M	F	B	2	4	2.5	N	4.2	3.3

CHUTE	U	M	F	B	3	4	1.0	N	2.8	3.3
CITED	U	M	F	B	1	5	1.0	N	17.0	3.3
COLON	U	M	F	B	3	4	2.5	N	3.4	3.3
COMIC	U	M	F	B	1	4	2.5	N	11.6	3.3
CULTS	U	M	F	B	1	4	2.5	N	2.1	3.3
MAIZE	U	M	F	B	1	3	1.5	N	2.4	2.5
MEDIC	U	M	F	B	2	3	1.5	N	3.8	2.5
MIDST	U	M	F	B	2	5	1.0	N	12.5	2.5
MOCHA	U	M	F	B	1	4	0.0	N	1.1	2.5
NICHE	U	M	F	B	1	3	0.5	N	3.9	7.2
NOBLE	U	M	F	B	1	3	1.5	N	17.1	7.2
NOTCH	U	M	F	B	1	4	0.5	N	4.4	7.2
NOVEL	U	M	F	B	1	3	3.0	N	41.0	7.2
NYLON	U	M	F	B	1	3	1.5	N	2.5	7.2
NYMPH	U	M	F	B	1	3	1.5	N	0.9	7.2
DIALS	C	M	F	H	1	5	2.0	12	1.4	3.8
DIETS	C	M	F	H	2	4	1.5	16	3.3	3.8
DIZZY	C	M	F	H	1	5	1.0	17	6.2	3.8
DRUMS	C	M	F	H	1	4	1.5	16	9.9	3.8
FLIER	C	M	F	H	1	4	2.5	19	1.9	2.4
FUZZY	C	M	F	H	1	4	1.5	19	6.4	2.4
GLORY	C	M	F	H	1	6	0.5	19	19.4	1.9
HABIT	C	M	F	H	1	4	0.5	17	18.8	5.1
HAWKS	C	M	F	H	3	5	1.5	8	2.4	5.1
KNOCK	C	M	F	H	1	3	2.0	14	32.6	0.5
LOGIC	C	M	F	H	1	4	0.0	17	15.3	4.1
SAUCE	C	M	F	H	1	4	2.5	15	25.1	6.5
SAUCY	C	M	F	H	1	3	1.0	15	1.0	6.5
SIREN	C	M	F	H	1	4	2.0	17	3.7	6.5
SMELT	C	M	F	H	3	4	1.5	16	1.5	6.5
SMOKY	C	M	F	H	1	5	1.5	16	3.8	6.5
SOULS	C	M	F	H	1	7	2.5	20	16.2	6.5
STERN	C	M	F	H	2	3	1.5	15	13.1	6.5
STIRS	C	M	F	H	2	6	2.5	14	2.0	6.5
SUGAR	C	M	F	H	1	4	0.5	12	44.7	6.5
ACUTE	U	M	F	H	1	7	0.5	N	9.4	8.0
ANNEX	U	M	F	H	1	4	0.5	N	1.1	8.0
ASIDE	U	M	F	H	1	4	2.5	N	50.1	8.0
AUGHT	U	M	F	H	2	2	2.5	N	0.3	8.0

DEITY	U	M	F	H	1	4	0.5	N	1.5	3.8
DENSE	U	M	F	H	1	4	2.0	16	8.1	3.8
DEVIL	U	M	F	H	1	6	1.0	11	26.1	3.8
DRAWS	U	M	F	H	1	11	2.5	15	11.8	3.8
FATAL	U	M	F	H	1	4	1.0	N	13.0	2.4
FROST	U	M	F	H	1	4	1.5	7	7.0	2.4
FUROR	U	M	F	H	1	4	1.0	N	2.3	2.4
GHOST	U	M	F	H	1	5	1.0	24	21.6	1.9
KAPPA	U	M	F	H	2	2	0.0	N	2.1	0.5
KIOSK	U	M	F	H	1	4	0.0	N	1.0	0.5
LEVEE	U	M	F	H	2	4	2.0	N	1.3	4.1
LIBEL	U	M	F	H	1	3	1.0	5	1.6	4.1
LIMBO	U	M	F	H	2	3	2.5	N	2.3	4.1
SCRUB	U	M	F	H	2	8	1.0	19	6.8	6.5
SOLID	U	M	F	H	1	12	1.5	17	47.8	6.5
STRUT	U	M	F	H	2	2	1.5	N	2.1	6.5
ORGAN	C	M	F	T	1	4	1.0	12	10.4	7.6
PANEL	C	M	F	T	1	6	2.0	17	27.9	2.1
PERCH	C	M	F	T	2	5	2.5	8	2.3	2.1
PLUCK	C	M	F	T	1	5	2.5	13	2.1	2.1
PLUGS	C	M	F	T	1	6	2.5	25	2.4	2.1
PROOF	C	M	F	T	1	4	2.0	23	33.9	2.1
PROUD	C	M	F	T	1	6	0.5	22	59.7	2.1
PUPIL	C	M	F	T	2	2	1.0	4	9.2	2.1
QUAIL	C	M	F	T	2	2	0.0	10	2.1	0.1
QUILL	C	M	F	T	1	4	2.0	6	4.2	0.1
RAFTS	C	M	F	T	2	4	2.0	17	2.4	6.3
RELAX	C	M	F	T	1	4	1.0	20	44.3	6.3
RHYME	C	M	F	T	1	3	1.0	17	3.5	6.3
RIOTS	C	M	F	T	1	6	2.0	20	3.5	6.3
TAXIS	C	M	F	T	2	3	2.0	7	2.0	9.3
TRUER	C	M	F	T	1	9	0.5	14	1.2	9.3
TWIST	C	M	F	T	1	8	1.5	17	15.3	9.3
WAGON	C	M	F	T	1	4	1.0	13	28.7	1.7
WAIST	C	M	F	T	1	4	1.5	14	10.6	1.7
WRECK	C	M	F	T	1	5	2.0	9	9.7	1.7
INLAY	U	M	F	T	1	5	0.0	N	0.4	7.6
INPUT	U	M	F	T	1	4	0.0	N	12.7	7.6
IRONS	U	M	F	T	1	9	1.5	N	3.9	7.6
IVORY	U	M	F	T	1	5	0.0	12	8.9	7.6

OPERA	U	M	F	T	2	4	0.5	16	27.0	7.6
PIANO	U	M	F	T	2	2	0.5	14	28.5	2.1
PIOUS	U	M	F	T	1	4	0.0	10	4.5	2.1
PRIOR	U	M	F	T	2	3	0.5	N	35.6	2.1
PULSE	U	M	F	T	2	6	1.5	N	15.1	2.1
QUASH	U	M	F	T	2	2	1.0	N	0.6	0.1
QUERY	U	M	F	T	1	4	0.0	N	1.5	0.1
REIGN	U	M	F	T	1	3	2.5	N	5.7	6.3
RENEW	U	M	F	T	1	4	0.0	N	3.6	6.3
REPEL	U	M	F	T	1	5	2.5	N	3.4	6.3
RIGID	U	M	F	T	1	4	0.5	11	15.1	6.3
RUNIC	U	M	F	T	2	3	1.5	N	0.1	6.3
UNDUE	U	M	F	T	1	3	0.0	N	5.4	2.7
UPSET	U	M	F	T	1	13	0.5	12	41.3	2.7
WHEEL	U	M	F	T	1	5	1.0	14	38.0	1.7
WHIFF	U	M	F	T	1	4	0.0	N	2.1	1.7
CAPES	C	M	M	B	2	2	12.0	20	3.2	3.3
CARED	C	M	M	B	2	7	10.5	18	14.6	3.3
CASTS	C	M	M	B	1	7	8.5	20	4.1	3.3
CHEAT	C	M	M	B	1	4	5.5	18	8.8	3.3
CHEEK	C	M	M	B	1	3	4.5	16	15.2	3.3
CHICK	C	M	M	B	1	3	8.0	12	11.7	3.3
CHIPS	C	M	M	B	2	7	8.0	20	13.9	3.3
CLICK	C	M	M	B	1	3	9.0	21	8.4	3.3
CODES	C	M	M	B	1	4	9.5	20	13.4	3.3
CREEK	C	M	M	B	1	3	5.5	13	11.5	3.3
CROOK	C	M	M	B	1	4	5.0	11	3.9	3.3
CROPS	C	M	M	B	1	7	8.0	13	13.1	3.3
CROWN	C	M	M	B	1	13	8.5	8	15.1	3.3
CRUST	C	M	M	B	1	4	4.5	7	4.7	3.3
CUBES	C	M	M	B	2	4	5.0	11	3.9	3.3
CURED	C	M	M	B	2	4	6.0	15	6.1	3.3
NESTS	C	M	M	B	1	6	5.5	4	2.6	7.2
NOISE	C	M	M	B	1	4	5.5	14	37.4	7.2
NOSES	C	M	M	B	1	4	9.5	15	5.3	7.2
NOTES	C	M	M	B	1	8	4.5	17	54.8	7.2
CARVE	U	M	M	B	1	3	5.5	N	3.6	3.3
CASTE	U	M	M	B	1	3	9.0	N	2.5	3.3
CHASE	U	M	M	B	3	7	7.0	N	22.2	3.3

CHUMP	U	M	M	B	2	4	6.5	N	1.9	3.3
CITES	U	M	M	B	1	5	6.5	N	7.3	3.3
CLACK	U	M	M	B	1	3	8.5	N	0.5	3.3
CLAPS	U	M	M	B	1	4	11.0	N	1.2	3.3
CLASH	U	M	M	B	1	3	6.0	N	4.3	3.3
CLEAT	U	M	M	B	1	4	5.5	N	0.7	3.3
CLING	U	M	M	B	1	3	7.0	N	4.1	3.3
CLINK	U	M	M	B	2	2	8.0	N	1.2	3.3
CLIPS	U	M	M	B	2	8	6.0	N	3.7	3.3
CLUNK	U	M	M	B	1	3	5.5	N	0.5	3.3
COILS	U	M	M	B	2	2	5.5	N	1.7	3.3
COPES	U	M	M	B	2	4	12.0	N	2.1	3.3
CORPS	U	M	M	B	1	3	6.5	N	44.3	3.3
CRANK	U	M	M	B	1	3	6.5	N	3.5	3.3
CURES	U	M	M	B	2	4	8.5	N	2.4	3.3
NAKED	U	M	M	B	1	5	5.5	N	32.3	7.2
NAPPY	U	M	M	B	3	3	4.5	N	0.6	7.2
DIVER	C	M	M	H	1	3	9.5	11	2.0	3.8
DOPED	C	M	M	H	1	5	9.0	15	0.7	3.8
DOWNS	C	M	M	H	2	11	5.5	10	6.1	3.8
DROVE	C	M	M	H	2	3	5.5	11	46.0	3.8
FEVER	C	M	M	H	1	3	5.0	14	17.8	2.4
FLAKE	C	M	M	H	1	3	7.0	9	1.5	2.4
FLOWS	C	M	M	H	1	4	9.0	13	7.3	2.4
GRADE	C	M	M	H	1	4	10.0	14	40.1	1.9
GRAZE	C	M	M	H	2	3	8.5	11	1.3	1.9
HEELS	C	M	M	H	2	7	5.5	10	16.9	5.1
HOLDS	C	M	M	H	2	10	6.0	17	36.6	5.1
HOOPS	C	M	M	H	1	5	7.0	11	3.0	5.1
KILLS	C	M	M	H	1	6	9.0	19	12.7	0.5
LANES	C	M	M	H	1	7	9.0	15	4.4	4.1
LINED	C	M	M	H	2	21	9.5	18	14.0	4.1
LONGS	C	M	M	H	2	6	4.5	13	1.1	4.1
LUSTY	C	M	M	H	1	3	5.0	8	1.5	4.1
SNOWS	C	M	M	H	1	5	5.0	14	3.3	6.5
SOCKS	C	M	M	H	2	3	7.5	4	12.7	6.5
STOVE	C	M	M	H	2	3	6.5	11	12.0	6.5
ALLEY	U	M	M	H	2	6	5.0	18	12.7	8.0
DATES	U	M	M	H	2	6	10.5	20	23.3	3.8

DEALS	U	M	M	H	2	6	7.5	19	18.0	3.8
DEANS	U	M	M	H	1	4	6.0	N	2.6	3.8
FACES	U	M	M	H	1	5	11.0	20	53.0	2.4
FADED	U	M	M	H	1	4	7.0	23	12.1	2.4
FLING	U	M	M	H	1	4	6.0	13	2.7	2.4
FORGE	U	M	M	H	2	4	5.5	N	6.0	2.4
FUSES	U	M	M	H	2	4	5.5	N	1.7	2.4
GRAIN	U	M	M	H	1	8	8.5	11	16.2	1.9
HALTS	U	M	M	H	2	3	5.5	2	2.2	5.1
HOOKS	U	M	M	H	1	6	10.5	17	4.3	5.1
JOKES	U	M	M	H	1	4	6.5	8	15.2	0.2
JUMPS	U	M	M	H	1	8	7.0	12	5.9	0.2
KICKS	U	M	M	H	1	4	6.0	17	6.7	0.5
SCOOP	U	M	M	H	1	6	5.5	13	5.6	6.5
SHADE	U	M	M	H	1	8	9.5	11	17.6	6.5
SLACK	U	M	M	H	2	6	9.0	N	6.9	6.5
SNORT	U	M	M	H	1	3	5.5	N	2.0	6.5
STARK	U	M	M	H	1	3	10.0	N	8.5	6.5
PACKS	C	M	M	T	2	6	10.0	23	5.4	2.1
PATCH	C	M	M	T	1	6	8.0	21	15.7	2.1
PEACH	C	M	M	T	1	4	8.0	10	5.2	2.1
PICKS	C	M	M	T	2	8	9.0	13	12.5	2.1
POUCH	C	M	M	T	1	3	5.5	11	2.5	2.1
PURSE	C	M	M	T	1	4	7.0	12	16.1	2.1
RAINS	C	M	M	T	1	4	10.5	18	5.9	6.3
ROAST	C	M	M	T	1	5	4.5	16	9.8	6.3
ROCKS	C	M	M	T	2	7	7.5	20	25.5	6.3
RUSTY	C	M	M	T	1	3	5.5	17	9.5	6.3
TAMER	C	M	M	T	1	4	5.0	13	0.5	9.3
TRACE	C	M	M	T	2	5	8.5	20	20.8	9.3
WASTE	C	M	M	T	1	4	6.0	19	48.6	1.7
WAVED	C	M	M	T	2	8	10.0	13	11.5	1.7
WEARS	C	M	M	T	1	5	12.5	16	11.2	1.7
WEEDS	C	M	M	T	2	4	6.5	14	5.6	1.7
WINGS	C	M	M	T	1	9	8.5	8	24.1	1.7
WISER	C	M	M	T	2	6	4.5	10	4.2	1.7
WITCH	C	M	M	T	1	3	9.0	22	13.8	1.7
WOODS	C	M	M	T	1	5	6.5	14	35.2	1.7
PAGES	U	M	M	T	2	6	8.0	10	31.5	2.1
PAIRS	U	M	M	T	1	5	5.0	9	10.5	2.1

PARKS	U	M	M	T	1	4	7.5	21	16.5	2.1
PEERS	U	M	M	T	2	4	7.0	12	11.6	2.1
PINKS	U	M	M	T	2	6	8.0	23	2.7	2.1
PIPES	U	M	M	T	2	9	6.0	15	8.0	2.1
POLLS	U	M	M	T	1	5	8.5	N	14.2	2.1
POOLS	U	M	M	T	2	8	4.5	13	9.3	2.1
RAGED	U	M	M	T	1	5	9.0	6	3.6	6.3
RELAY	U	M	M	T	1	5	5.0	13	3.8	6.3
TARRY	U	M	M	T	2	4	8.5	N	0.6	9.3
TIMER	U	M	M	T	1	3	7.5	14	4.3	9.3
TREAD	U	M	M	T	1	3	6.5	12	3.5	9.3
TUNES	U	M	M	T	1	6	6.5	14	5.9	9.3
TWINE	U	M	M	T	1	3	5.0	18	1.2	9.3
WAGER	U	M	M	T	1	3	8.5	5	2.8	1.7
WAILS	U	M	M	T	1	4	11.5	N	1.3	1.7
WARDS	U	M	M	T	1	4	9.5	N	2.1	1.7
WOUND	U	M	M	T	2	3	8.5	12	26.5	1.7
WRACK	U	M	M	T	3	4	4.5	N	0.6	1.7

Appendix C: Stimuli Characteristics for the Non-First Letter Keystroke Analyses

Columns 2-4: Levels for the whether number of associates were controlled or not, number of meanings, and number of orthographic neighbors factors. Columns 5 and 6: Wordsmyth counts. Coulmns 7-9: Word level information. Columns 10-12: Position, letter frequency, and bigraph frequency of the top row keystroke analyzed. Columns 13-15: Position, letter frequency, and bigraph frequency of the home row keystroke analyzed. Columns 16-18: Position, letter frequency, and bigraph frequency of the bottom row keystroke analyzed.

	Factor Levels			Wordsmyth Counts					Top Row Keystroke			Home Row Keystroke			Bottom Row Keystroke		
Word	Assoc. Control	Meanings	Orth. NBRs.	Defs.	Senses	# Orth. NBRs.	# of Assocs.	Word Freq.	Pos.	Letter Freq.	Bigraph Freq.	Pos.	Letter Freq.	Bigraph Freq.	Pos.	Letter Freq.	Bigraph Freq.
ACIDS	C	F	F	1	1	1.0	15	4.6	3	7.6	2584.8	4	3.8	4973.8	2	3.3	4190.8
ADORN	C	F	F	1	2	2.0	23	1.2	4	6.3	14029.7	2	3.8	3823.1	5	7.2	1996.7
AVOID	C	F	F	1	2	1.5	17	54.0	3	7.6	663.5	5	3.8	4973.8	2	1.1	2198.1
FOAMY	C	F	F	1	2	1.0	19	1.9	2	7.6	4940.4	3	8.0	792.7	4	2.5	3141.0
GAUZE	C	F	F	1	2	2.0	13	1.5	3	2.7	1357.9	2	8.0	1783.0	4	0.1	35.2
NAIVE	C	F	F	1	2	2.0	15	7.4	3	7.6	4995.8	2	8.0	3442.6	4	1.1	2600.5
PRISM	C	F	F	1	2	1.0	13	1.4	2	6.3	4008.4	4	6.5	10074.1	5	2.5	528.8
SCOLD	C	F	F	1	1	1.5	13	1.1	3	7.6	7186.0	5	3.8	3068.8	2	3.3	1353.1
SHRUB	C	F	F	1	1	2.0	8	1.5	4	2.7	1246.6	2	5.1	3240.7	5	1.5	977.9
SNAIL	C	F	F	1	2	2.5	8	1.6	4	7.6	4995.8	3	8.0	3442.6	2	7.2	201.4
TANGY	C	F	F	1	1	2.5	13	1.3	5	1.7	190.5	4	1.9	10966.9	3	7.2	20619.9
YACHT	C	F	F	1	1	0.5	11	5.7	5	9.3	1455.0	4	5.1	5423.6	3	3.3	4190.8
CHURN	U	F	F	1	1	1.0	N	1.1	3	2.7	560.6	2	5.1	5423.6	5	7.2	1996.7
DOGMA	U	F	F	1	2	0.0	N	3.2	2	7.6	1853.7	3	1.9	801.2	4	2.5	44.3
ENDOW	U	F	F	1	2	0.5	N	1.4	5	1.7	3303.8	3	3.8	12296.2	2	7.2	14075.4
ENSUE	U	F	F	1	2	1.0	N	1.5	4	2.7	2450.1	3	6.5	4950.4	2	7.2	14075.4
FOCAL	U	F	F	1	1	2.5	N	5.2	2	7.6	4940.4	5	4.1	10245.7	3	3.3	1573.0
HYENA	U	F	F	1	1	0.5	N	1.1	2	1.7	290.1	5	8.0	3442.6	4	7.2	14075.4
ITEMS	U	F	F	1	2	1.5	N	52.0	2	9.3	10385.1	5	6.5	844.4	4	2.5	3314.8
KNIFE	U	F	F	1	1	0.5	13	52.2	5	12.5	2021.1	4	2.4	1349.5	2	7.2	377.2
LANKY	U	F	F	1	1	2.5	N	1.5	5	1.7	124.5	2	8.0	5517.8	3	7.2	20619.9
SCOWL	U	F	F	1	1	0.5	N	1.1	4	1.7	3303.8	5	4.1	144.6	2	3.3	1353.1
SPASM	U	F	F	1	2	2.5	N	1.9	2	2.1	1758.0	4	6.5	8958.6	5	2.5	528.8
WACKY	U	F	F	1	1	2.5	N	2.1	5	1.7	124.5	4	0.5	1950.0	3	3.3	4190.8
BARNS	C	F	M	1	1	6.0	13	2.2	3	6.3	12531.8	5	6.5	4950.4	4	7.2	1996.7
CANDY	C	F	M	1	1	6.5	14	24.3	5	1.7	448.7	4	3.8	12296.2	3	7.2	20619.9
COUCH	C	F	M	1	1	7.0	12	19.3	2	7.6	7186.0	5	5.1	5423.6	4	3.3	1616.8
DUCKY	C	F	M	1	1	5.0	16	1.1	5	1.7	124.5	4	0.5	1950.0	3	3.3	1616.8

FAMED	C	F	M	1	1	8.0	13	3.9	4	12.5	7870.2	2	8.0	1403.1	3	2.5	3141.0
FARMS	C	F	M	1	2	5.5	12	12.9	3	6.3	12531.8	5	6.5	844.4	4	2.5	1617.6
LOANS	C	F	M	1	2	4.5	10	21.4	2	7.6	3532.1	5	6.5	4950.4	4	7.2	20619.9
LUCKS	C	F	M	1	2	9.0	16	2.0	2	2.7	1174.8	5	6.5	767.7	3	3.3	1616.8
SHOVE	C	F	M	1	2	6.0	2	6.5	3	7.6	5249.3	2	5.1	3240.7	4	1.1	2155.0
STUCK	C	F	M	1	1	6.5	18	43.8	3	2.7	1954.7	5	0.5	1950.0	4	3.3	1616.8
SWANS	C	F	M	1	2	4.5	13	1.2	2	1.7	196.5	5	6.5	4950.4	4	7.2	20619.9
WAKEN	C	F	M	1	2	6.0	9	0.3	4	12.5	3051.3	3	0.5	1271.4	5	7.2	14075.4
BLAME	U	F	M	1	2	6.5	22	44.3	5	12.5	7870.2	3	8.0	5517.8	4	2.5	3141.0
CHOCK	U	F	M	1	1	7.5	N	0.5	3	7.6	5249.3	2	5.1	5423.6	4	3.3	1573.0
CLUCK	U	F	M	1	2	6.5	N	1.6	3	2.7	1174.8	5	0.5	1950.0	4	3.3	1616.8
CRICK	U	F	M	1	1	7.5	N	1.5	3	7.6	7114.4	5	0.5	1950.0	4	3.3	7879.9
CROCK	U	F	M	1	2	8.5	N	1.5	3	7.6	7468.4	5	0.5	1950.0	4	3.3	1573.0
DANDY	U	F	M	1	2	6.5	N	7.7	5	1.7	448.7	2	8.0	2191.5	3	7.2	20619.9
FLOWN	U	F	M	1	1	4.5	N	5.5	4	1.7	3303.8	2	4.1	519.5	5	7.2	968.5
GABLE	U	F	M	1	2	6.0	N	1.2	5	12.5	8465.5	2	8.0	1783.0	3	1.5	2024.4
HICKS	U	F	M	1	1	6.5	N	3.2	2	7.6	6381.2	5	6.5	767.7	3	3.3	7879.9
HUNCH	U	F	M	1	2	5.0	N	5.7	2	2.7	560.6	5	5.1	5423.6	4	3.3	4100.6
SHORN	U	F	M	1	1	6.5	N	1.2	4	6.3	14029.7	2	5.1	3240.7	5	7.2	1996.7
SHUCK	U	F	M	1	1	6.0	N	0.6	3	2.7	560.6	2	5.1	3240.7	4	3.3	1616.8
ARENA	C	M	F	1	4	1.0	20	11.0	2	6.3	12531.8	5	8.0	3442.6	4	7.2	14075.4
CLIMB	C	M	F	1	4	1.5	15	19.0	3	7.6	6854.9	2	4.1	1436.9	5	1.5	966.3
CLUBS	C	M	F	1	6	2.0	22	19.4	3	2.7	1174.8	2	4.1	1436.9	4	1.5	977.9
CYCLE	C	M	F	1	5	0.5	17	20.4	2	1.7	426.4	4	4.1	1436.9	3	3.3	100.5
HABIT	C	M	F	1	4	0.5	17	18.8	4	7.6	1140.3	2	8.0	10324.2	3	1.5	2024.4
LIBEL	C	M	F	1	3	1.0	5	1.6	2	7.6	6854.9	5	4.1	5238.3	3	1.5	694.1
LOGIC	C	M	F	1	4	0.0	17	15.3	2	7.6	3532.1	3	1.9	801.2	5	3.3	7879.9
ORGAN	C	M	F	1	4	1.0	12	10.4	2	6.3	14029.7	4	8.0	1783.0	5	7.2	20619.9
PLUCK	C	M	F	1	5	2.5	13	2.1	3	2.7	1174.8	5	0.5	1950.0	4	3.3	1616.8
SAUCE	C	M	F	1	4	2.5	15	25.1	3	2.7	1357.9	2	8.0	3775.4	4	3.3	1616.8
SAUCY	C	M	F	1	3	1.0	15	1.0	3	2.7	1357.9	2	8.0	3775.4	4	3.3	1616.8
SMELT	C	M	F	3	4	1.5	16	1.5	5	9.3	1135.0	4	4.1	5238.3	2	2.5	528.8
ADOBE	U	M	F	1	3	1.0	N	1.5	3	7.6	1853.7	2	3.8	3823.1	4	1.5	877.4
ALIGN	U	M	F	1	4	1.0	N	1.9	3	7.6	6854.9	2	1.9	2820.7	4	7.2	704.0
FANCY	U	M	F	1	4	2.0	19	22.3	5	1.7	426.4	2	8.0	1403.1	3	7.2	20619.9
GIANT	U	M	F	1	4	2.0	17	26.7	5	7.6	1257.0	3	8.0	3051.9	4	7.2	20619.9
LILAC	U	M	F	1	3	1.0	N	2.1	2	7.6	6854.9	4	8.0	5517.8	5	3.3	4190.8
LUCID	U	M	F	1	3	1.5	N	2.3	2	2.7	1174.8	5	3.8	4973.8	3	3.3	1616.8

MAGIC	U	M	F	1	4	1.5	23	43.8	4	7.6	1257.0	2	1.9	2316.2	5	3.3	7879.9
QUACK	U	M	F	2	3	2.5	5	4.8	2	2.7	1074.3	5	0.5	1950.0	4	3.3	4190.8
REIGN	U	M	F	1	3	2.5	N	5.7	3	7.6	1765.7	4	1.9	2820.7	5	7.2	704.0
ROCKY	U	M	F	2	6	2.5	13	15.4	5	1.7	124.5	4	0.5	1950.0	3	3.3	1573.0
SNARL	U	M	F	2	4	2.0	N	0.9	4	6.3	12531.8	5	4.1	976.8	2	7.2	201.4
THUMB	U	M	F	1	3	1.5	8	12.6	3	2.7	560.6	2	5.1	29934.8	5	1.5	966.3
BUNCH	C	M	M	1	3	6.5	15	35.7	2	2.7	1766.5	5	5.1	5423.6	4	3.3	4100.6
BURNS	C	M	M	1	7	5.0	20	21.3	2	2.7	1766.5	5	6.5	4950.4	4	7.2	1996.7
CHICK	C	M	M	1	3	8.0	12	11.7	3	7.6	6381.2	2	5.1	5423.6	4	3.3	7879.9
CHUCK	C	M	M	3	7	6.0	20	18.6	3	2.7	560.6	5	0.5	1950.0	4	3.3	1616.8
CLICK	C	M	M	1	3	9.0	21	8.4	3	7.6	6854.9	5	0.5	1950.0	4	3.3	7879.9
DOWNS	C	M	M	2	11	5.5	10	6.1	3	1.7	3303.8	5	6.5	4950.4	4	7.2	968.5
KICKS	C	M	M	1	4	6.0	17	6.7	2	7.6	1194.2	4	0.5	1950.0	3	3.3	7879.9
LOCKS	C	M	M	2	6	10.0	14	7.6	2	7.6	3532.1	5	6.5	767.7	3	3.3	1573.0
MUCKY	C	M	M	1	4	5.0	18	2.7	5	1.7	124.5	4	0.5	1950.0	3	3.3	1616.8
SANDY	C	M	M	1	3	6.0	8	16.3	5	1.7	448.7	4	3.8	12296.2	3	7.2	20619.9
SOCKS	C	M	M	2	3	7.5	4	12.7	2	7.6	3395.0	4	0.5	1950.0	3	3.3	1573.0
TICKS	C	M	M	3	4	7.5	10	1.9	2	7.6	11289.4	5	6.5	767.7	3	3.3	7879.9
BLOWN	U	M	M	1	4	4.5	N	12.8	4	1.7	3303.8	2	4.1	2103.4	5	7.2	968.5
BRICK	U	M	M	1	4	7.5	14	15.4	3	7.6	7114.4	5	0.5	1950.0	4	3.3	7879.9
CLOWN	U	M	M	1	4	4.0	N	8.3	4	1.7	3304.0	2	4.1	1437.0	5	7.2	968.5
CORNS	U	M	M	2	6	8.5	14	1.1	2	7.6	7186.0	5	6.5	4950.4	4	7.2	1996.7
FLICK	U	M	M	1	3	5.5	18	3.8	3	7.6	6854.9	2	4.1	519.5	4	3.3	7879.9
FLOCK	U	M	M	2	6	6.0	N	7.7	3	7.6	3532.1	5	0.5	1950.0	4	3.3	1573.0
GRAND	U	M	M	1	4	6.0	17	51.7	2	6.3	1746.2	5	3.8	12296.2	4	7.2	20619.9
LOCUS	U	M	M	1	3	4.5	N	3.4	4	2.7	1542.9	5	6.5	4434.2	3	3.3	1573.0
PRICK	U	M	M	1	5	5.5	N	6.1	2	6.3	4008.4	5	0.5	1950.0	4	3.3	7879.9
SNARE	U	M	M	2	3	7.0	N	1.0	4	6.3	12531.8	3	8.0	3442.6	2	7.2	201.4
SPANK	U	M	M	2	2	7.0	19	2.1	2	2.1	1758.0	3	8.0	3434.6	4	7.2	20619.9
SPANS	U	M	M	2	6	6.0	12	3.0	2	2.1	1758.0	5	6.5	4950.4	4	7.2	20619.9