Drawing out the Temporal Signature of Induced Perceptual Chunks

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Abstract

The effect of chunking in the process of drawing was investigated using a task domain consisting of simple hierarchically organized geometrical patterns, which participants learnt to draw. The study focused upon the latencies between drawing actions. A new technique for the identification of chunks was devised, based on patterns in the magnitudes of latency. The technique was significantly better than the use of a fixed latency threshold. It was discovered that there was a strong temporal signature of the underlying chunk structure and that effects of learning were evident.

Introduction

The concepts of chunking and the limited size of memory span, first proposed by Miller (1956), underlie many modern theories of human cognition. The phenomenon has been verified in many domains (Vicente, 1988), and at most levels of cognitive processing in both humans and nonverbal organisms (Terrance, 1991). Given the pivotal role of chunking it is, perhaps, surprising that there has been little research on the role of chunking in drawing. There has been some research on: low level motor behaviour constraints on drawing (Van Sommers, 1984), the functions of drawing in high level cognitive tasks such as design (Akin, 1986) and, drawing as a reflection of children's cognitive development (Goodnow & Levine, 1973). However, direct investigations of the role of chunking in the process of drawing are absent.

We are conducting studies that begin to address this deficiency in the understanding of this prominent human ability. Our approach is to have participants learn specially designed named geometric shapes, from verbal labels, which they then reproduced from memory – drawing out induced perceptual chunks. This paper focuses on whether chunks are apparent in temporal characteristics of drawing. Specifically, we have discovered that the absolute duration of pauses between drawing actions, the latencies, reflects the hierarchical structure of induced chunks and reveals the effect of learning by the composition of chunks. Further, we have found that local maxima in the latencies are better discriminators of boundaries between separate chunks than a fixed latency threshold.

Previous work on chunking and drawing will first be discussed to set the context for this work.

Chunking and Pausing Behaviour

The idea that latencies or pauses might be a means by which one can segment data in order to discriminate chunk boundaries, arises from research conducted by Chase and Simon (1973). They defined an operational method by which to characterize chunks. In recall and memory tasks the latency distributions for between-glance placements of chess pieces, which were taken to indicate boundaries between chunks, were significantly longer than within-glance placements, which were taken to indicate items within a chunk. Hence, items with pauses below a certain threshold could be considered as within a chunk and items with longer pauses above the threshold could be considered to be between chunks. The use of thresholds as one means to distinguish chunks has been supported by studies in domains such as: Chess (Chase & Simon, 1973; Gobet, 1998), Go (Rittman, 1976,1980), and electronic circuits (Egan & Schwartz 1979).

A significant pause can be defined as a latency greater than a static threshold typically within the range 2 to 5 seconds (Card, Moran, & Newell, 1983). Although, in studies of drawing, researchers have used pauses as low as 1 second to segment data into chunks (Akin, 1986; Ullman, 1990).

However, there are difficulties with the use of latency thresholds to differentiate chunk boundaries (Holden, 1992; Gobet, 1998). Firstly, there is no one threshold that holds across different task domains (Chase & Simon 1973; Egan & Schwartz, 1979; Akin, 1986; Ullman, 1990; Gobet & Simon, 1998). However, a threshold can be found by training participants in a domain and then testing them (Reitman, 1976). Secondly, it has been observed that when learning takes place, as in the transition from novice to expert, latency times for chunk boundaries decrease (Chase & Simon 1973; Reitman, 1976; Egan and Schwartz, 1979). Thresholds must be changed dynamically over time to cope with individual differences. Thirdly, for memories that are organized hierarchically (Palmer, 1977), the higher the chunk is in the hierarchy the more subchunks it contains and the longer it takes to recall (Reitman, 1976). A single threshold might elicit chunks at one level but not its subchunks or higher order chunks.

This paper proposes an alternative approach to thresholds for the identification of chunks using

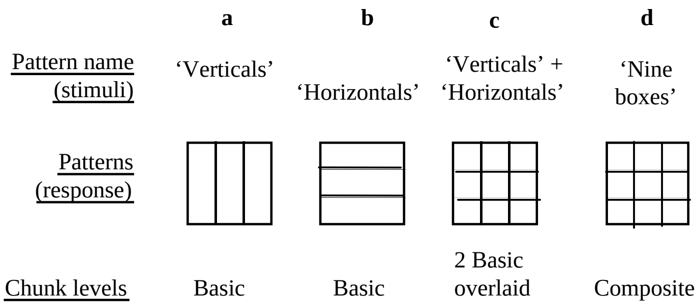


Figure 1. Examples of types of patterns from the shape drawing domain.

latencies between drawing actions. By focusing on patterns over successive latencies the new technique can overcome some of the limitations of fixed thresholds.

Here, we define latency for a particular element as the time between lifting the pen off the paper at the end of one element and the time at which the pen touches the paper again at the beginning of marking the current element. The same holds for mouse button up and down actions when dragging a line on a computer screen.

The Nature of Drawing

Intuitively and theoretically there are various reasons to believe that understanding the role of chunks in the process of drawing will be a challenge. First, consider the recall and the drawing of a perceptual chunk given a verbal label for that chunk. A succession of processes are involved, including: the recall of the chunk, the planning of the order in which to produce the elements of a chunk, the planning of where to draw each individual element, and, the execution of the motor actions to make a mark for the element. It seems likely that such a sequence of processes would hide any hierarchical organization of chunks in long-term memory. Second, it appears unlikely that these processes would occur in a strictly serial manner and they are likely to be interleaved to different extents. This will probably mask any attempt to analyze the underlying structure of chunks. Third, the process of planning might in itself interfere with the recall of chunks and so potentially prevent each chunk from being recalled in a single burst of activity (Reitman, 1976). One might reasonably assume that analysis of latencies within this area would reflect planning and action, rather than chunking. Fourth, the processes of mark making, including subjects sensitivity to methods of motor efficiencies (Akin, 1986), might interact with the recall of chunks. For example, the speed of making a mark may vary with the hierarchical chunk level of the current element being drawn and so interfere with the apparent recall latency of the next element.

Despite all these reasons, the experiment reported here demonstrates that the duration of pauses between the drawing of individual elements is highly indicative of the structure of chunks in memory. It appears that far from diluting any information about the underlying organization of chunks, the duration of latencies in the process of drawing seems to provide a temporal signature for perceptual chunks.

The next section presents the drawing domain and task used in the experiments. The following section describes the discovery of patterns in the latencies that were highly suggestive of a temporal signature of chunks. The experiment and results that demonstrate the reality of these patterns are then considered in turn. The implications of the findings are considered in the final discussion section.

Domain, Stimuli and Tasks

To study the behavioural manifestations of chunking in drawing a special 'shape' domain consisting of named geometric patterns was devised; examples are shown in Figure 1. Initially participants were taught six basic patterns, such as Figure 1a and 1b, and they drew several examples of them when given their names. They were then shown pairs of names of basic patterns to draw overlaid upon each other; Figure 1c. These composite patterns were then separately named; Figure 1d. The composite patterns consist of four lines and a typical drawing task involves drawing a sequence of different composite patterns in a row beside a written list of names.

Features of the design of the domain that make it highly suited to the study of chunking behaviour are: (1) the use of simple predefined shapes to make errors in recall or drawing easily identifiable, (2) the definition of a fixed hierarchy of patterns, with known nesting of levels and no overlapping of elements over chunks at the same level, (3) the participants learn the patterns, so the specific chunks and their organisation is known *a priori*, (4) verbal labels are used as stimuli to make participants recall the perceptual chunk from long-term memory, (5) the composite chunks consist of a small number of sub-chunks to keep demands on working memory low, (6) the outline square is drawn before each pattern to ensure drawing processes are fully engaged when the pattern is produced.

The domain has three chunk levels: (level 1) lines within chunks, (level 2) basic patterns, (level 3) composite patterns. Thus, every line was coded depending on the order in which they were drawn. The first and second drawn lines of a two line basic pattern were coded level 2 and 1, respectively. The code for the four lines of two basic patterns overlaid was 2-1-2-1, respectively. The four lines of a composite pattern were coded 3-1-2-1, respectively, on the assumption that the composite consisted of two sub-chunks.

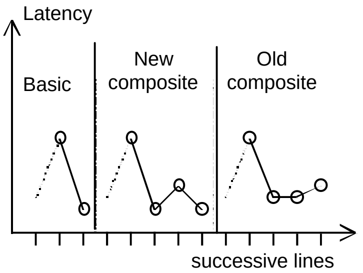


Figure 2. Temporal signature for different chunks

Motivating Observations and Hypotheses

The experiment reported below consists of two experiments (taken together here for the sake of brevity and coherence). The first was a pilot in which latency and other measures were examined in an exploratory manner. In graphs for various measures based on data from each individual participant on a single task (i.e., raw un-aggregated data), it was noticed that certain patterns of latencies appeared to be common and were related to the participants' induced chunks. Figure 2 illustrates the patterns found. Local maxima in latencies, *peaks*, tended to be associated with the first line of basic and composite chunks. A peak was operationally defined as any latency whose magnitude was at least 10% greater than the mean of the preceding and following latencies. With new just learnt composite chunks there were two peaks, matching the two sub-chunks, with the second peak being smaller. With old composites that had been drawn many times, and so learnt well, the second peak tended to disappear.

Although the patterns illustrated in Figure 2 were not universal they were sufficiently frequent to suggest that some temporal signature of chunks would be found by analyzing latencies. In particular, we propose three hypotheses: (H1) Peaks may be an effective way to discriminate chunks. Are peaks better than fixed latency thresholds for identifying chunk boundaries? (H2) Hierarchical chunk levels may be reflected in the absolute magnitude of latencies. (H3) The learning of chunks may be apparent in changes of latencies over time. Further, (H4) if the temporal signature of perceptual chunks is real then it should be apparent when different drawing media are used. The purpose of the experiment was to test these hypotheses.

Experiment

The first two hypotheses were tested by using the shapes domain described above. The third hypothesis concerning learning was tested by comparing performance over two successive sessions in which the same patterns were learnt and reinforced. The fourth hypothesis was tested by using two different drawing interfaces – pen and paper drawing versus keyboard and mouse driven on-screen computer drawing, henceforth *freehand* and *computer* groups, respectively.

The participants were unpaid volunteers, 4 male and 4 female aged 30-45. Equal numbers were assigned to the computer and freehand groups.

Apparatus

The computer drawing used a specially written program on a Macintosh G3 computer. To draw a line, participants first used the keyboard to select the type of line to be drawn (i.e. horizontal, vertical or diagonal) by pressing a key. The line was then drawn using a standard mouse dragging action, with the line "rubber banding" between the endpoints.

The freehand drawing used a high spatial and temporal resolution drawing tablet (Wacom UD tablet) connected to a PC computer running a specially written data capture and analysis program.

In both cases the computers recorded detailed spatial and temporal data to enable the drawn patterns to be identified and for the latencies to be found.

Procedure

Participants were tested individually and each completed two sessions. The participants were given a period of familiarization with the given drawing apparatus. In session 1, in order to learn the patterns participants completed drawings of several basic patterns. This was followed by a further 6 drawings of both and basic and composite patterns. In the session 2, there were 18 drawings consisting of multiple patterns. The stimuli were presented on printed sheets or by verbal instructions.

Results

Peaks versus thresholds: H1 and H4

Consider first the overall distributions of latencies for elements within chunks (level 1) and between chunks (levels 2 and 3). For data aggregated over participants in the same group and over all the tasks in each session, Table 1 shows various measures for these distributions. Between chunk latencies are greater than within chunk latencies, across session and interface type. All the distributions are skewed towards lower latency values. This pattern is similar to that found in other domains (e.g., Chase and Simon, 1973; Reitman, 1976; Egan and Schwartz, 1979), so it is appropriate to analyze this domain using thresholds to identify chunk boundaries. As latency distributions were skewed, median latencies rather than the mean latencies were used in the analysis.

As expected, the median latencies were shorter for freehand drawing versus computer drawing because of the extra decisions and motor actions required with the computer drawing interface.

Table 1: Between and Within Chunk Latency Distributions (milliseconds)

	Group	Computer		Freehand	
	Session	1	2	1	2
Between Chunk	N	217	309	197	315
	Mean	1647	1188	2017	899
	Median	1347	931	989	620
	SD	1237	892	2985	1677
Within Chunk	N	214	325	186	286
	Mean	814	686	1113	413
	Median	681	665	475	389
	SD	958	340	3657	169

As the number of chunks is defined by the stimuli set an 'optimum threshold' can be set to distinguish chunk boundaries on an individual participant and session basis. The threshold is set so that the number of items above the threshold equals the number of known chunk items. Table 2 gives the thresholds found for each participant. Note the differences across sessions and the differences between individuals within sessions. As would be expected, the threshold for free hand is generally less than that for computer drawing.

Table 2: Optimal thresholds (milliseconds) for each participant

Computer sessions			Freehand session		
	1	2		1	2
P1	600	800	P5	400	400
P2	1400	800	P6	600	600
P3	1400	1200	P7	800	800
P4	1600	1200	P8	600	600

How do peaks compare with the use of latency thresholds as methods to discriminate chunks? Information theory (Wickens, 1993) provides a convenient way to measure how well each method performs by treating each as a system that is attempting to transmit information about items within chunks and items at the boundaries between chunks. By using conditional probabilities, information theory takes into account not only true positives and negatives (e.g., peak–>between chunks, ~peak–> within chunk) but also false positives and negatives (peak–>within chunk, ~peak–>between chunks). Using the optimal thresholds given above and the prior knowledge about which items were chunks or not, the correctness of each individual identification was determined. The same was done for peaks. Hence, the 'quality' (information transmission/channel capacity) of each method was computed (Wickens, 1993). The ideal quality, for all participants across the sessions, was almost unity because the numbers of within and between chunk items were nearly equal.

Table 3: Quality of chunk discrimination by the two methods (bits)

	Peaks		Threshold	
	Session 1	Session 2	Session 1	Session 2
Computer				
P1	0.628	0.444	0.398	0.247
P2	0.503	0.186	0.155	0.080
P3	0.306	0.195	0.261	0.092
P3	0.355	0.117	0.247	0.071
Freehand				
P5	0.460	0.595	0.133	0.274
P6	0.400	0.620	0.168	0.331
P7	0.671	0.622	0.321	0.205
P8	0.410	0.238	0.217	0.138

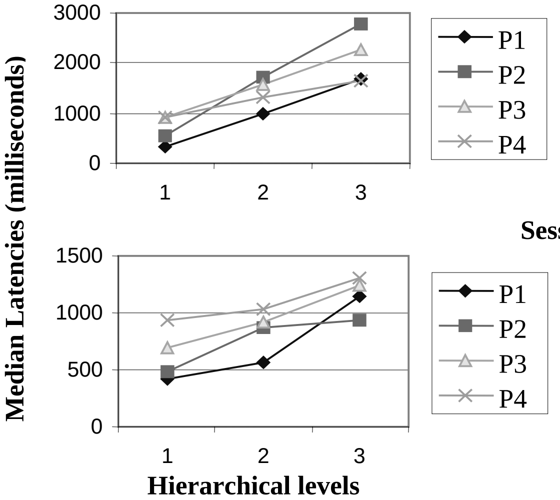
Table 3 shows that for each participant in each session under each drawing interface, the quality of the discrimination with peaks was better than that using fixed latency thresholds. Although there were just four participants in each group, two-tail t tests were performed to determine whether the peak method gave a significantly higher quality of discrimination than the threshold method. This was indeed the case for the freehand drawing in sessions 1 and 2 (p=.005 and p=.02, respectively) and computer drawing in session 2 (p=.018). For computer drawing in session 1 the difference was approaching significance (p=.07).

The results demonstrate: (H1) that peaks are a more effective way to discriminate chunk boundaries, and (H4) the temporal signature of perceptual chunks is apparent across different drawing media.

Chunking levels and learning: H2 & H3

Figures 3 and 4 show graphs of the median latencies against different chunk levels for each drawing interface and across each session. With one exception, for every participant in each session with both drawing interfaces, the median latencies increased with increasing chunk level. Using Page's test for ordered median alternatives as applied to the different levels of the chunk hierarchy (levels 1, 2, and 3) there was a significant increasing trend in the latencies for the computer drawing in both sessions; in both cases L=56, p=.001 (n=4, k=3). Similarly for Freehand drawing in session 1 L=56, p=.001 and session 2 L=55, p=.01 (n=4, k=3). The difference between the medians holds not only at the group levels but also at an individual level. Using the data for each participant, the Kruskal-

Session 1



Session 2

Figure 3: Computer drawing

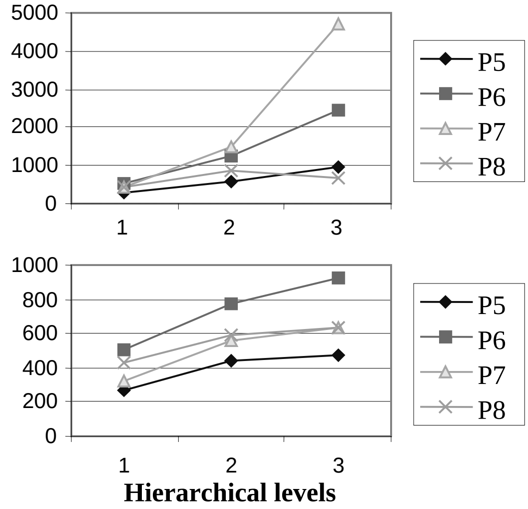


Figure 4: Freehand drawing

Wallis-H test was used to test whether the latency distributions for the hierarchical levels were significantly different. As shown in Table 4, the results of the test for all participants were significant in both sessions and regardless of the mode of drawing. Comparing the graphs in Figures 3 and 4 across the two sessions for each mode of drawing, it is clear that the magnitudes of latencies drop. (Note that the latency scale ranges differ.)

The results demonstrate: (H2) that the magnitude of latencies reflect the hierarchical chunk level.

Table 4: Analysis of participants' latency distributions over the hierarchical levels; Kruskal-Wallis H

Mode of Drawing	Participant	Session 1 n	Session 1 $\chi 2$	Session 2 n	Session 2 $\chi 2$
Computer	P1	118	60.3^{+}	184	61.48^{+}
	P2	102	20.5^{+}	158	21.0^{+}
	P3	105	28.7^{+}	145	24.5^{+}
	P4	106	19.9^{+}	146	15.2^{+}
Freehand	P5	92	21.3^{+}	124	45.3^{+}
	P6	107	24.0^{+}	187	88.9^{+}
	P7	91	32.3^{+}	175	59.4^{+}
	P7	93	29.1^{+}	115	29.9^{+}

$^{+}p \leq .001$, df=2 in all cases

Table 5 presents median latencies for participants using each mode of drawing for each chunk hierarchy level and summarises the analysis. The latencies decreased over sessions regardless of the hierarchical level. The differences between participants performance over the two sessions was assessed by applying the Mann-Whitney U test (one-tailed); for the freehand drawing group the decrease in median latencies is significant at all chunk levels and for the computer drawing group the decrease is significant at chunk level-2 and level-3.

The results demonstrate: (H3) that the learning of chunks is apparent in the changes of latencies over time.

Table 5: Comparison of the latencies between sessions at each hierarchical level

Mode of Drawing & measure	Hierarchical levels 1 S1	1 S2	2 S1	2 S2	3 S1	3 S2
Computer						
Median	681	665	1131	865	1720	1114
N	542		401		117	
U	33523		14540^{+}		1079^{+}	
Z	-0.88		-4.44		-3.09	
Free-hand						
Median	472	389	989	584	1042	658
N	473		341		110	
U	19664^{+}		12228^{+}		626.5*	
Z	-4.869		-6.591		-1.88	

*p<.05, $^{+}p \leq .001$

Discussion

A specially designed geometric shapes domain has been used to study chunking behaviour in drawing. Participants learnt named patterns that were assumed, reasonably, to have been stored in memory as induced perceptual chunks. The differences in the distributions of recall latencies for elements within chunks and those between chunks is similar to patterns of latency distributions found in other domains (e.g., Chase and Simon, 1973; Reitman, 1976; Frey, 1976; Egan and

Schwartz, 1979; Akin 1986; Ullman, 1990; Gobet, 1998). Similarly, optimal latency thresholds that could be used to identify chunks were found to vary with participants, depending on the nature of the drawing interface and on the effect of learning.

It was discovered that peaks (local maxima in latencies) were significantly better discriminators of chunks than fixed thresholds. The contrast between the approaches would be even starker, if, as would normally be the case, the number of chunks was not known *a priori* and used to set the optimal threshold. Peaks have the advantage that they use only local information about the relative magnitude of latencies to discriminate chunks. Whether the peaks method constitutes a general technique applicable beyond drawing awaits further studies in other domains.

It was found that in drawing there was a strong temporal signature of perceptual chunks in the latencies. The level of an element in the chunk hierarchy is reflected in the magnitude of the latency, the higher the level the longer the pause. The effect is sufficiently prominent to yield significant differences in individual participant data. The effect of learning is also evident in the changes in the absolute magnitude of latencies at specific chunk levels. The changes to the latencies appear to indicate when two chunks have been compiled into a single composite chunk.

These effects were consistent over the different modes of drawing, which suggests that the temporal signature reflects the structure of chunks in memory, and that the other processes of drawing, such as planning, are organized on the basis of the chunk structure. The process of drawing may magnify the effect of chunk structure rather than diminish or distort it. It seems plausible that the (sub) processes of drawing may operate in a largely serial fashion. Latencies between chunks may be longer than within chunk latencies because they encompass more sub-processes.

Further work is addressing the robustness and generalisability of the phenomena outlined in this paper. The temporal signature of chunking has been found to be apparent in other drawing domains, such as diagrammatic representations for problem solving (Lane, Cheng & Gobet, 2001).

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References

Akin, O. (1986). *Psychology of Architectural Design*. London, Pion Ltd.

Card, S. K, Moran, T. P., & Newell, A. (1983). *The Psychology of Human-Computer Interaction*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Chase, W., & Simon, H. (1973). Perception in Chess. *Cognitive Psychology* 4,55-81.

Egan, D. E., & Schwartz, B. J. (1979). Chunking in the recall of symbolic drawings. *Memory and Cognition*, 7(2), 149-158.

Gobet, F. (1998). Expert Chess Memory: Revisiting the Chunking Hypothesis. *Memory*, 6(3), 225-255.

Gobet, F., & Simon, H (1998). Pattern Recognition makes search possible: Comments on Holding. *Psychological Research*, 61, 204-208.

Goodnow, J., & Levine, R. (1973). The Grammar in Action: Sequence and syntax in Children's Copying. *Cognitive Psychology*, 4, 82-98.

Holden, D. H. (1992). Theories of chess skill. *Psychological Review*, 54, 10-16.

Lane, P. C. R, Cheng, P. C-H., & Gobet, F. (2001). Learning Perceptual Chunks for Problem Decomposition. In *Proceedings of the Twenty-Third Annual Conference of the Cognitive Science Society* (this volume)

McLean, R., & Gregg, L. (1967). Effects of Induced chunking on Temporal Aspects of Serial Recitation. *Journal of Experimental Psychology*, 74(4), 455-459.

Miller, G. A. (1956). The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information. *The Psychological Review*, 63, 81-97.

Palmer, S. (1977). Hierarchical Structure in Perceptual Representation. *Cognitive Psychology*, 9,441-474.

Reitman, J. (1976). Skilled perception in Go: Deducing Memory Structures from Inter-Response Times. *Cognitive Psycholog*y, 8, 357-381.

Suwa, M., & Tversky, B. (1996). What architects see in their sketches: Implications for design tools. *CHI'96- Human Factors in computing systems*, Vancouver, British Columbia, Canada, ACM.

Terrance, H. (1991). Chunking During Serial Learning by a Pigeon: I. Basic Evidence. *Journal of Experimental Psychology: Animal Behaviour Process*, 17(1), 81-93.

Tulving, E. (1962). Subjective organization in free recall of unrelated words. *Psychological Review*, 69, 344-354

Ullman, D., Wood, S., & Craig, S. (1990). The Importance of Drawing in the Mechanical Design Process. *Computer & Graphics*, 14(2), 263-274.

Van Sommers, P. (1984). *Drawing and Cognition*. New York, Cambridge University Press.

Vicente, K. (1988). Adapting the memory recall paradigm to evaluate interfaces. *Acta Psychologica*, 69, 249-278.

Wickelgren, W. (1964). Size of rehearsal group and short-term memory. *Journal of Experimental Psychology*, 68,413-419.

Wickens, C. D. (1993). *Engineering psychology and human performance*, 2nd ed. New York: HarperCollins