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Influences of Cultural Artifacts and Social Practices on Number Conceptualisation: Experimental and Ethnographic Approaches to Everyday Numeric Cognition

by

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Graduate Program in Psychology

Submitted in partial fulfilment
of the requirements for the degree of
Doctor of Philosophy

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Abstract

The current investigations coordinate math cognition and cross-cultural approaches to mathematical thinking to examine the linkages between numeric and non-numeric processes, and how these linkages are modified by cultural artifacts such as writing and by socially situated math numeracy practices. Two main studies investigate these issues.

The first study examined whether Arabic right-left writing practices and English left-right practices influence the spatial orientation of the mental number line. There is considerable research with English and French monoliterates which shows that numbers are conceptualised as points on mental number line which runs from left to right with smaller numbers associated with the left side and larger numbers associated with the right side (Bachtold, Baumuller, & Brugger, 1998; Brysbaert, 1995; Dehaene & Akhavein, 1995; Dehaene, Bossini, & Giraux, 1993). These associations between numerals and points on a number line have been termed the SNARC effect (Dehaene et al., 1993). In an attempt to explain why the mental number line has a left-to-right directionality, Dehaene et al. (1993) studied whether one's literacy practices influenced the strength and direction of the SNARC effect. Results of their study showed a SNARC effect in French monoliterates and a weakened SNARC effect among highly skilled French-Persian biliterates who used both the French left-right and the Persian right-left writing systems. These results suggest that the Persian right-to-left literacy practices weaken the SNARC effect. Extending Dehaene et al's., line of research, the current investigation examined the influences of the Arabic right-to-left writing system on number conceptualisation in three groups: an Arabic Monoliterate group who read and write from right-to-left, a Adult Arabic-English Biliterate group, an English Monoliterate group. Two additional groups, a Lebanese Illiterate group who could read numbers only and a Child Arabic-English Biliterate group, were investigated to examine how level of language skill affects the mental number line. Results from the Arabic Monoliterate group revealed, for the first time a complete reversal of the SNARC effect (Reverse SNARC), such that small numbers were associated with the right side of the number line and large numbers were associated with

the left side. Further evidence that directionality of writing influences the mental number line is also partially supported by findings from Arabic-English Biliterates who only showed a trend towards the Reverse SNARC effect. Results from the Child Biliterate group, who had minimal ESL skills, showed a Reverse SNARC. Finally, the Illiterate Lebanese group showed neither a Reverse SNARC nor a SNARC effect, revealing that reading and writing skill are needed to give rise to the spatialisation of numbers (Study 1c).

A secondary finding of the current investigation, concerned the SNARC effect in English monoliterate groups. The findings of the Oral Numeral Only study (Study 1a), unexpectedly showed only a non-significant trend towards the SNARC for English Monoliterates. Two follow-up studies with English Monoliterates showed that the strength of the SNARC effect is influenced by the requirement to make bimanual responses and the presence of number words in the stimulus. Further research is required to examine how the strength of the SNARC effect varies with task demands.

The second separate line of research extended studies by Saxe (1991) which found that Brazilian child street sellers, who have little school-based literacy skills, were not skilled at identifying Arabic numerals presented in isolation without a bill context. In the current series of studies, the speeded bill and numeral recognition and conceptualisation processes of two Lebanese Seller groups, a Traditional and Modernising group and two Non-Seller control groups was investigated. Ethnographic observations of the two seller groups revealed that Traditional Sellers have orally-based numeracy practices which strongly emphasise the linkages between numerals and the bill context, while the numeracy practices of Modernising Sellers emphasised paper-based numeracy which involves reading monetary values outside the context of currency practices. Looking first at the results of the speeded numeral recognition study (Study 2a), the results showed that both the Traditional Sellers and Non-Sellers were more skilled at naming monetary values in a bill context. Furthermore, they were slower to name a monetary value presented in isolation without a bill context. These findings reveal that the visuospatial properties of the bill are a context for orthographic

recognition processes. This strong emphasis on the context in which numerals are embedded is not observed in the two Modernising groups. Turning to the priming study (Study 2b) which assessed number conceptualisation, Arabic numbers representing monetary values primed the naming of a bill only for the Modernising Sellers. This finding suggests that paper-based selling practice leads to skill in handling monetary values outside the context of currency. The other priming result which assessed whether the body of a currency bill (with its orthographic properties occluded) could prime the whole bill, showed that the Traditional Sellers, and Modernising Sellers and Non-Sellers those who have most experience with currency, show significant levels of this type of priming. The Traditional Non-Seller group who had least experience with currency, were not primed by the body of the bill. Results of these studies show that bill and numeral recognition and conceptualisation are influenced by everyday numeracy practices.

Key words: cross-cultural maths, cultural artifacts, ethnographic and experimental methods, everyday numeracy practices, SNARC effect.

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Influences of Cultural Artifacts and Social Practices on Number Conceptualisation: Experimental and Ethnographic Approaches to Everyday Numeric Cognition

Chapter 1: Introduction

This investigation studies the linkages between numeric and non-numeric processes and how these linkages are shaped by artifact use and social practices. The adult maths cognition literature which considers the cognitive architecture of number processing, and more broadly, mathematical thinking has given little consideration to how numeric and non-numeric aspects of cognition get linked and coordinated. Similarly, in the past three decades of research in animal and infant numeric cognition, emphasis has been placed on showing that animals and infants have abstract representations of numbers, at least in the subitizing range, which are independent of spatial, perceptuo-motor, processing, and time perception (for reviews of large bodies of empirical research see Gallistel & Gelman, 1992; Roberts, 1998; Wynn, 1998). In comparison to these research traditions, the main purpose of the current investigation is to show that the development of complex numeric competencies in adults involve necessary coordinations and linkages between numeric and non-numeric processes such as spatial thinking, and visuospatial processing.

More recent theory and empirical research in the maths cognition literature, and more broadly in cross-cultural psychology, cognitive linguistics, and philosophy, challenge the view that the core cognitive mechanisms used for mathematical and quantitative thinking can function independently of the same conceptual and perceptual-motor processes that enable other cognitive functions such as perceptual encoding, categorisation, reasoning, and decision making (Ascher, 1991; Beach, 1995; T. Carraher, Schliemann, & D. Carraher, 1987; Cole, Gay, Glick, & Sharp, 1971; Ernest, 1998; Greeno, 1991; Greeno, Benke, Engle, Lackappelle, & Wiebe, 1998; Hatano, Amaiwa, & Shimizu, 1987; Hishitani, 1990; Hutchins, 1995a, 1995b; Lancy, 1983; Lakoff, 1997; Lakoff & Nunez, 1999; Lave, 1988; Miller & Paredes, 1996; Millroy, 1991; Saxe, 1982,1985, 1991; Saxe, Guberman, & Gearhart, 1987). The challenges posed by these investigators of math psychology is the broad movement which provides empirical and theoretical basis for the current research.

Starting with the challenges posited by experimental maths psychologists, the linkage between spatial thinking and number processing is investigated by a number researchers working independently of one another. The view that spatial processing supports number knowledge acquisition is central to the infant maths cognition literature which has established that the spatial information about the location of objects and the mapping from objects to numerosity is the basis for the development of number concepts (Gelman & Gallistel, 1978; Starkey, Spelke, & Gelman, 1990). Also, in the mathematics education literature, there is research which shows that success in early arithmetical processes is dependent on acquiring mental representations of numerals that fall along a mental number line analogous to a physical number line (Resnick, 1983; Griffin, Case, & Siegler, 1994). Turning to the adult maths cognition literature which is the focus of the current investigations, Dehaene and colleagues and a number of other independent researchers, provide a further extension of this view by postulating that number concepts themselves have visuospatial properties (Dehaene, 1992; 1997; Dehaene, Bossini, & Giraux, 1993; Gallistel & Gelman, 1992; Krueger, 1989; Moyer & Landauer, 1967; Restle, 1970; Seron, Pesenti, Noel, Deloche, & Cornet 1992). The view is that numbers invoke not only a sense of magnitude or quantity but also a sense of space. This view and the empirical evidence to support it, directly challenge the view that number concepts are aperceptual or amodal abstractions (McCloskey, 1992; McCloskey, Macaruso, Whetstone, 1992; McCloskey, Sokol, & Goodman, 1986). A number concept is considered amodal if it does not include notation specific properties such as Arabic numeral features or number word features. Proponents of the amodal view of number concepts also posit the subtler position that numerical inputs are obligatorily translated via an anumeric notation specific module that functions completely independently of the magnitude or numerosity code. The implication of an amodal approach is that numerical processes are relatively autonomous from non-numeric, non-quantative processes. This approach to number cognition has more recently been challenged by a number of researchers working within the maths cognition research tradition (Campbell, 1994; Campbell & Clark, 1992; Dehaene, 1992, 1997; Dehaene, Bossini, Giraux, 1993; Dehaene & Cohen, 1995). The research used to challenge the amodal approach will be described in more detail in the introductions to the current studies.

Beyond the maths cognition literature and among cultural psychologists, there has been a long tradition which treats mathematical thinking as interconnected with other socio-cognitive processes. These approaches have shown how mathematical thinking arises out of historic socio-cultural practices and is shaped by artifact use and goal-directed social and work practices (Ascher, 1991; Beach, 1995; Cole, Gay, Glick, & Sharp, 1971; Hatano, Amaiwa, Shimizu, 1987; Hishitani, 1990; Hutchins, 1995a, 1995b; Lancy, 1978; Lave, 1977; 1988; Millroy, 1991; Saxe, 1982,1985, 1991; Stevenson & Stigler, 1992). Some of this work is grounded in recent theoretical developments in cultural psychology (Cole, 1996), cultural cognition (Hutchins, 1995a, 1995b), situated learning (Lave, 1988; Lave & Wenger, 1991), practice theory (Scribner, 1983; Valsiner, 1987), and cross-cultural psychology (Denny, 1986; 1991). These researchers all begin with the assumption that the individual mind cannot be studied outside the physical and social contexts in which it functions because artifacts and social interaction place specific cognitive demands on thought processes. The main contributions from cultural approaches to mathematical thinking have been to show that there are cultural contexts and cultural practices that influence the development of complex mathematical skills such as arithmetic and problem solving. In contrast to the experimental math cognition tradition, cultural psychologists have not actively developed theories and empirical methods to investigate whether cultural practices affect basic on-line mathematical processes.

Looking more broadly to interdisciplinary approaches to mathematical thinking, the amodal view of mathematical thinking has been seriously challenged by cognitive linguists (Lakoff, 1987; 1997; Lakoff & Nunez,1997). Lakoff offers a cognitive linguistic approach to mathematical thinking which provides an account of how abstract mathematical thought and mathematical theories develop out of everyday experience. In Lakoff's conceptual metaphor theory, sensorimotor concepts ground all abstract thought, including mathematical thought (Lakoff & Johnson, 1980; Lakoff, 1987; Lakoff & Nunez, 1997). According to Lakoff, the sensorimotor concepts that are necessary for mathematical thinking arise out of the structure of everyday experience such as forming collections, counting objets in spatial arrays, taking steps in a given direction, and so on. Lakoff argues that these experiences lead to embodied concepts where the symbolic structure of a concepts is related to the perceptuo-motor processes from which it originates. These embodied concepts get linked through metaphorical extensions to more abstract concepts, such as numbers. For example, Lakoff posits that we metaphorically conceptualise numbers as points in space, hence the connection between spatial and numeric processing. In agreement with some of Lakoff's views, Paul Ernest (1997, 1998), a philosopher of mathematics and a proponent of a social constructivist approach to mathematics education, supports the view that mathematical concepts are embodied and arise out of neuropsychological characteristics of the brain. Extending this view, Ernest also claims that mathematical thinking necessarily arises out of social interaction. For Ernest, social processes enable higher levels of mathematical thinking that extend far beyond embodied concepts. This view contrasts with Lakoff's claim that mind and body-based mathematics is elaborated and extended to more complex forms through metaphorical processes that are grounded in and constrained by embodied concepts. Lakoff disagrees with Ernest's social constructivist approach and claims that metaphorical processes and not social processes enable advanced mathematical thinking. The differences in Lakoff's and Ernest's approach to mathematical psychology are not of central concern here, however, they are mentioned to illustrate the complexities of mathematical psychology once we begin to consider how mathematical thinking is dependent on non-mathematical non-quantative processes.

Overview of the Two Main Studies Which Investigate the Linkages Between Numeric Cognition and Other Thought Processes

I will examine two independent lines of research which challenge the amodal view. The first line of research extends recent developments in the maths cognition literature which examines the relationship between numeric and spatial thinking. Working in this research tradition, Dehaene (1992; Dehaene & Cohen 1995) offers empirical evidence, and a detailed computational and neurologically constrained model, which posits that numbers have spatial properties which are automatically activated during any kind of quantitative processing. These linkages have been empirically investigated in a number of studies which show that numbers are conceptualised as points on an analogical number line, with small numbers on the left and larger numbers increasing towards the right. This association between numbers and points in space has been term the Spatial-Numerical Association of Response Codes effect, or the SNARC effect. (Bachtold, Baumuller, Brugger, 1998; Brysbaert, 1995; Dehaene, 1989 Dehaene & Akhavein, 1995; Dehaene, Bossini, & Giraux, 1993; Dehaene & Cohen, 1991; Dehaene, Dupoux, & Mehler, 1990). Dehaene et al. offer some preliminary evidence that directionality of writing influences how numbers are associated with points on a spatially oriented number line. They offer some evidence that the Western European left-to-right writing system gives rise to a number line which is orientated from left to right with smaller numbers associated with left side of space and larger numbers associated with the right side of space. Further evidence from a series of studies with French-Persian bilinguals who read and write Persian from right-to-left suggests that these associations may be partially reversed by the influences of a right-to-left writing system (Dehaene et al., 1993). In the present studies, the influences of the English left-to-right writing system on the spatialisation of number concepts in English Monoliterates will be compared to the influences of the Arabic right-to-left writing system on number spatialisation in Arabic Monoliterates and Arabic-English Biliterates. These studies will be referred to as the Spatial Processing and Number Conceptualisation (SNARC) studies. The first study in the SNARC series, herein referred to as the Oral Numeral Only SNARC study, will investigate the influences of the Arabic right-to-left writing system on number conceptualisation in an Arabic monoliterate group residing in Lebanon. The influences of both the Arabic right-to-left writing system and the English left-to-right writing system will also be investigated in Arabic-English biliterates residing in Lebanon. In addition to studying the influences of directionality of writing on the SNARC effect in these three groups, the influences of language skill on the SNARC effect was examined in two additional Lebanese groups. An Illiterate group who could read numerals but not printed text was studied to assess whether the SNARC effect can be observed in illiterate groups. Finally, a child Arabic-English biliterate group who could read and write Arabic but had minimal levels of English-as-a-second language skill was assessed. In addition to the Oral Numeral Only study, two follow-up studies were conducted because the SNARC effect did not reach statistical significance in the English Monoliterate. In these follow-up studies attempts were made to assess, for the first time, what task demands effect the strength of the SNARC effect in different numerical judgement tasks.

The second line of research is situated in the cross-cultural mathematics literature. It will extend Saxe's (1991) research into the maths of selling practice among Brazilian child candy street sellers. These studies will examine how numerical recognition skills are affected by various socially situated numeracy practices. In particular, the current investigation build upon previous studies that examined how child street sellers, who practice orally-based paperless numeracy, named currency bills and numerals presented without the bill context. Saxe found differences in the numeracy skills of candy sellers and schooled non-sellers who practiced literacy-based numeracy, and postulated that the numeric skills of sellers arise from cultural practices with currency and numerals (Saxe, 1982, 1985, 1989, 1991). Saxe's research with Brazilian candy sellers, and the social constructivist approach to mathematical thinking which tries to account for quantitative thinking in a way which is true to everyday social practices is the critical starting point for the current studies. The current two investigations (described in Chapters 4 and 5) extend Saxe's research in three ways. First, speeded rather than off-line number and bill recognition processes will be investigated for the first time. The focus on automatic processes in the current studies has received little attention in social constructivist approaches to quantitative thinking, nor are they taken up in Saxe's research. Second, the numeric skills of two seller groups who engage in different numeracy practices will be compared to assess whether orally-based compared to literacy-based numeracy affects bill and numeral recognition. Third, the relationship between bill and numeral recognition and conceptualisation will be studied. In the first study, herein referred to as the Bill and Numeral Recognition study, I will investigate speeded bill and orthographic numeral recognition processes in a Traditional Lebanese seller group who engages in orally-based paperless numeracy practices similar to those observed among Saxe's street sellers. The second group is a Modernising Lebanese seller group who practices literacy-based numeracy which involves thinking about monetary values outside the context of currency. These distinct numeracy practices will be described in the ethnographic component of the study. The second study, herein referred to as the Large Number Concept Priming study, will investigate whether the speeded recognition processes observed in the first study are related to differences in number conceptualisation. This study involves reanalysing the data from the recognition study to examine priming effects. A priming methodology provided a means of investigating number conceptualisation. The priming study will be described in full in the methods section of the Bill and Numeral study. This series of studies together will be referred to as the Currency Bill as Artifact in Maths of Selling Practice studies.

The SNARC and the Currency Bill as Artifact studies arise from completely independent lines of research. The SNARC studies are situated in traditional experimental approaches to number processing which have, until very recently, completely disregarded the influences of social practice and artifact use on numeric cognition. In comparison, the Currency Bill as Artifact studies are situated in social constructivist approaches to mathematical thinking which have little to say about automatic numeric processes and representational issues in the mind. Setting aside the various reasons for their separate development, in the current investigation both lines of research will be taken up because they offer empirical evidence for the linkages between quantitative and non-quantitative thinking. Furthermore, they empirically demonstrate that these linkages are shaped by cultural artifacts. These studies provide a starting point for investigating the role of cultural practices and artifact use on number processing. The SNARC studies will be reviewed first.

Chapter 2: Spatial Processing and Number Conceptualisation

A series of studies in the present research will investigate the SNARC effect and whether it is influenced by directionality of one's writing system. This linkage between numbers and spatial thinking has been observed by Dehaene and colleagues and by a number of independent researchers who use different types of numeric judgement tasks to assess number conceptualisation (Bachtold, Baumuller, Brugger, 1998; Brysbaert, 1995; Dehaene & Akhavein, 1995; Dehaene, Bossini, & Giraux, 1993; Dehaene & Cohen, 1991; Dehaene, Dupoux, & Mehler, 1990; Seron, Pesenti, Noel, Deloche, & Cornet, 1992). The SNARC effect has been theoretically interpreted in Dehaene's triple code model of number processing which posits that numbers may be represented as an auditory verbal word frame code, a visual Arabic number form, and an analogue magnitude code. Findings which show the SNARC effect are taken, by Dehaene (1992, 1997) as evidence for two features of number concepts. First, the SNARC effect reveals that a number's magnitude code has spatial properties. Second, this magnitude code is isomorphic to a number line that runs from left-to-right.

The view that the magnitude of a number has spatial properties is compatible with research by Seron, Pesenti, Noël, Deloche, and Cornet (1992) which examined the introspective accounts of how individuals mentally visualise numbers. One common feature of the introspective reports was the ordinal organisation of numerals on a linear scale which had a horizontal, and in some cases a vertical or a rectilinear structure. Similar stable visuospatial descriptions were gathered by Galton (1880) who studied the introspective reports of 80 male and female participants. Both of these visuospatial features of number forms are strongest for numerals below 10-12 suggesting that visuospatial features are associated with the higher frequency (but lower value) numerals.

The view that the magnitude code is analogous to a number line with visuospatial properties is accepted by many scholars. However, the specific characteristics of this representation, that is whether it is a linear, logarithmic, or a compressed number line, is still controversial (Dehaene, 1992; Dehaene & Mehler, 1992; Gallistel & Gelman, 1992; Krueger, 1989; Moyer & Landauer, 1967; Restle, 1970; Seron, Pesenti, Noël, Deloche, & Cornet, 1992). This debate is beyond the scope of the current investigation, but the general consensus that number concepts are like points on a number line serves as the starting point for studies into the SNARC effect.

The evidence which shows that number concepts are organised along a spatially oriented number line is the starting point for the first SNARC study which goes on to examine, for the first time, whether Arabic right-to-left writing practices lead to a reversal of the SNARC effect. Before the current Oral Numeral Only SNARC study is described the evidence which establishes that numbers are conceptualised as points on an analogical number line will be reviewed. I will then go on to evidence which shows that the directionality of this number line is influenced by the one's directionality of writing.

A Review of the Literature on the SNARC effect

The SNARC effect has been revealed in various number processing tasks which required subjects to: make parity (even/odd) judgements, classify numbers as larger or smaller than a fixed standard of reference, and finally tasks that required participants to judge whether two numerals have the same value or different values. All these tasks have been bimanual binary judgements tasks where the participant pressed a right-side button for one response and a left-side button for another response. The evidence for the SNARC effect for each type of task will be reviewed in turn. The task used to assess how numbers are spatialised in the current study of Arabic Monoliterate, Arabic-English Biliterate, Arabic Illiterate, and English Monoliterate groups was an oral version of Dehaene and Akhavein's (1995) same-different judgement task. The current study will be described once the evidence for the SNARC effect has been reviewed.

The SNARC Effect in Parity Judgement Tasks

The SNARC effect was first observed in a neuropsychological case study of an acalculic patient. In this study Dehaene and Cohen (1991) required their patient, N.A.U., to classify single digit numerals, ranging from 0-9, as odd or even numbers. N.A.U. was instructed to respond by tilting a joy stick to the left if the number was even and or to tilt to the right if the number was odd. The assignment of responses to even and odd judgements was reversed in a second block of trials to counterbalance for handedness effects. Results of this study showed that N.A.U. could not make parity judgements as evidenced by an overall error rate of 44.4%, a rate which did not differ from chance. However, despite the patient's inability to make parity judgements, a SNARC effect was found; target numerals ranging from 0-4 were responded to faster with leftward responses and numerals 5-9 were responded to faster with rightward responses. Dehaene and Cohen (1991) argued that the results show an automatic activation of a left-right oriented number line because smaller numerals, as judged by the relative magnitude of the entire set, were associated with leftward responses and larger numerals were associated with rightward responses.

This SNARC effect observed by Dehaene and Cohen (1991) has been observed in two other bimanual parity judgement studies with normal participants. Dehaene, Bossini, and Giraux (1993) used a parity judgement task where participants had to decide whether a numeral was even or odd by pressing one of two response keys. In order to control for handedness effects, in the first block of trials, the odd responses were made with the right hand and even responses were made with the left hand. In the second block of trials, the same participants received the reverse assignment such that odd responses where made with the left and even with the right hand. Half the participants received this ordering of the blocks, while the other half received the reverse order of the two blocks. Results showed that right handed French students responded 30 milliseconds faster to larger numerals (numbers 5, 6, 7, 8, and 9 in a set ranging from 0-9) with right-sided key responses compared to the left-sided key responses. The converse was true for smaller numbers (0, 1, 2, 3, 4); they were responded to faster with left-sided responses. To investigate whether the SNARC effect arises out of handedness effects, the same task was administered to 10 left-handed participants. They showed a SNARC effect similar to the effect observed with right handers.

Parity judgements and the strength of the activation of the magnitude code. It is significant that the SNARC effect was found in these parity judgement tasks since the numerical magnitude of the target numeral is irrelevant to parity judgements. This is taken as evidence by Dehaene (Dehaene et al. 1993, p. 380; Dehaene, 1992, p. 21) that the magnitude of a number, which includes its spatial properties, is automatically activated in number conceptualisation. The view that the magnitude code is automatically activated by Arabic numerals is also held by and implemented in the number processing models of McCloskey (1992), and of Gallistel and Gelman (1992) , and is supported by extensive research (Dehaene, 1989; Dehaene et al. 1993; Meck & Church, 1983; Moyer & Landauer, 1967; Restle, 1970). The nature of this magnitude code, that is whether it is amodal, as McCloskey argues, or a scalar mental number line, as Gallistel and Gelman (1992) postulate, or a logrithmic number line as Dehaene and Mehler (1992) argue, is not at issue in current investigation. Furthermore, the issue of whether the magnitude code involves an automatic counting mechanism is beyond the scope of the current discussion (although see Meck & Church, 1983; Gallistel & Gelman, 1992). At issue in the current investigation is the directionality of this number line, and what it reveals about the linkages between the magnitude code, which encodes numerosity in a yet undetermined way, and spatial processes. Evidence for this linkage is further revealed in numeric comparison tasks, which will be reviewed next.

The SNARC effect in Numeric Comparison Tasks

Evidence for the SNARC effect is also observed in numeric comparison tasks. The SNARC effect was examined by Dehaene, Dupoux, and Mehler (1990) in study that employed a bimanual numeric comparison task which required French participants to judge whether a target Arabic numeral, ranging from 31-99, is greater-than or less-than a fixed numeral, i.e., 65. In this task, in contrast to the parity judgement tasks described above, hand of response was a between-subjects factor such that one group of participants had to respond by pressing the right-sided key with their right hand when the target was larger than the standard of 65 (larger-right group). The second group responded to the larger numerals by pressing a left-sided key with their left hand (larger-left group). The results showed that reaction times were 100 msec faster for participants who made larger-than judgements with right-sided keys compared to left-sided keys. These results suggest that when large numbers are responded to with the left-sided key, the SNARC effect is weakened. The size of the effect observed in this study is rather large compared to the 30 msec effects observed in Dehaene et al.'s (1993) parity judgement study which controlled for handedness effects. Consequently, the results of Dehaene et al. (1990) must be interpreted with some caution because side-of-response was confounded with hand of response, such that all right-sided key responses were made with the right hand and all left-sided key responses were made with the left hand. It is not likely that the SNARC effect would disappear when handedness is controlled, since the effect was observed in the parity judgement tasks which counterbalanced for handedness effects and since other studies with left handed participants also showed the effect (Dehaene et al. 1993, study 4). However, the effect may be weaker than is suggested by these results. Moreover, the size of the effect may also be due, in part, to task demands. A comparison task may instantiate an analogical number line where magnitudes are spatially and serially ordered more readily than a parity judgement task where neither the serial order nor spatial properties are relevant to parity judgements.

The empirical research on the SNARC effect that has been reviewed up to this point has all been conducted by Dehaene and his colleagues with French participants, and although the effect has been observed in different tasks, evidence from researchers working independently of Dehaene is important for assessing the generalisability and robustness of the effect.

Brysbaert (1995) conducted a series of studies to investigate whether speed of numeral recognition was influenced by the magnitude of a number. Although the purpose of Brysbaert's study was not to investigate the SNARC effect, results from his study provide some supportive evidence for the effect. In his experiment 3, participants were presented with a numeral which ranged from 11-99 on the left or right side of the screen. When this numeral disappeared a second numeral was presented 200 ms later on the side of the screen opposite to where the previous numeral appeared. The participants had two response buttons, one for the right hand and one for the left hand. Their task was to press the button on the side of the smaller numeral; consequently they were required to make less-than judgements but not greater-than judgements. Results showed that participants were faster to respond to smaller numerals with their left hand than with their right hand. This version of the SNARC effect is not the same as the SNARC observed in the parity and numerical comparison tasks. Those studies showed the associations at both ends of the continuum, where smaller numbers were associated with left-sided responses and larger numbers were associated with right-sided responses. In comparison, Brysbaert's findings show that smaller numerals are associated with left-sided responses, and thus are conceptualised as points on the left side of a number line. Since the participants were not required to make greater-than judgements, the claim that larger numerals are associated with the right-side of the number line can only be an indirect inference, albeit one that is consistent with the findings of the SNARC research reviewed above.

Bachtöld, Baumuller, and Brugger (1998) investigated how numbers were spatialised in a task where participants are trained to think about numbers either as indicators of distance (ruler version of task), or as indicators of time (clock version of the task). This study, in comparison to the parity judgement and numerical comparison tasks reviewed above, strongly emphasised the activation of a magnitude code since the participants were directly linking numerals to increasing magnitudes. For the ruler version of the task, participants are required to press a left-sided key with their left hand for numerals expressing distances that were shorter-than 6 cm, and a right-sided key with their right hand for numerals expressing distances longer than 6 cm. After 100 trials, shorter-than judgements were made with the right hand and longer than judgements were made with the left hand, such that left and right handed responses were not confounded with side of responding. During the practice trials a schematic representation of a ruler was displayed at the bottom of the screen to ensure that the numerals would be conceived as indicators of distance. In the clock version of the task a schematic representation of a clock was displayed at the bottom of the screen. In this version of the task participants were asked to press a button if the numeral stimulus was "earlier than 6 o'clock" and another button if the numeral was "later than 6 o'clock". Looking first at the ruler version of the tasks, results revealed that numerals smaller than 6 were responded to faster with the left hand, regardless of right or left-sided key presses, and larger numerals were responded to faster with the right hand. A possible interaction between hand of response and side of response was not assessed. The results of the clock version of the task, revealed no SNARC effect. Thus this study suggests that invoking the visual image of a ruler gives rise to a strong SNARC effect, and further shows that the SNARC effect is eliminated when a non-linear spatial image such as the image of a clock is invoked. This study shows for the first time that the SNARC effect is facilitated in contexts where there is a congruence between the left-right directionality of the physical stimulus and the internal mental code, and is inhibited (or at least not activated) when the physical stimulus is incongruent with a left-right oriented number line.

The SNARC Effect in a Same-Different Judgement Task

The same-different judgement task which was used by Dehaene and Akhavein (1995) to investigate the SNARC effect will be described in detail since it provides the basic rationale for the experimental design used in the current study to investigate the SNARC effect in the Arabic and English Monoliterate groups, Arabic-English Biliterate groups, and in Arabic Illiterate groups. In

Dehaene and Akhavein's study, 10 English Monoliterate university students judged whether two single digit numerals had the same or different numerical values, where one numeral was presented on the left side of the screen and the other numeral was presented on the right side. The participants pressed a button if the numerals had the same value and another button if they had different values.

The SNARC effect was assessed by investigating whether small Arabic numerals (1, 2) are automatically associated with the left side of space and large numerals (8, 9) are associated with the right side of space. This was studied by comparing the length of time it took participants to make difference judgements about numeral pairs when the smaller numeral was on the left side of the screen and the larger numeral was on the right (left-right condition), compared to the length of time it took them to make judgements when the smaller numeral was on the right side of the screen (right-left condition). The actual left-right pairs that the participants were presented with were: 1 8; 1 9; 2 8; and 2 9. The spaces between the numeral in each pair denoted here are meant to represent the space between the pairs on the screen. In the actual experiment, each of the numerals in the stimulus pairs appeared on the screen simultaneously and were positioned 7 centimetres apart. The right-left pairs were: 8 1, 9 1, 8 2, 9 2. Participants pressed a left-sided key for numerals with the same value, and a right-sided key for numerals that had different values. Left and right handed responses were counterbalanced with key responses such that "same" and "different" responses were made equally often with the left and right hand. In addition to presenting Arabic numeral pairs, three other types of pairs of left-right orientated and right-left oriented stimuli were presented to assess the effect of notation on number conceptualisation: number word-numeral (i.e., one 9, nine 1), number word-number word (i.e., one nine; nine one), and numeral-number word (i.e., 9 one, 1 nine).

The results of Dehaene and Akhavein's study relevant for our understanding of the SNARC effect showed that button responses were faster in the left-right condition, when the smaller numeral appeared on the left (i.e., 1 9), than in the right-left condition, when the smaller numeral appeared on the right (i.e., 9 1). The SNARC effect did not vary significantly with notation, which means that speed of left-right and right-left responses did not vary significantly across the four notation conditions; number word-numeral, number word-number word, numeral-number word, and numeral-numeral. Dehaene and Akhavein did not provide a breakdown of the response latencies for left-right and right-left responses across the stimulus conditions for both right and left hand responding, consequently it is not possible to derive a descriptive sense of how the SNARC effect may have varied across the notation conditions and whether it varied with left and right handed responses. In addition to the lack of descriptive data, there was a notable methodological difficulty in Dehaene and Akhavein's study. They did not have an equal number of "same" and "different" trials; one-third of the trials had the same numerical value and two-thirds had different numerical values. The accepted convention in reaction time studies is to have an equal number of each type of response. This method is used to curtail guessing strategies and to ensure that the participants are making their decision based on how they processed the stimulus instead of how well they can guess what stimulus will be presented next. The studies in the current investigation involve an equal number of "same"and "different" responses.

It is important to note, that for the same-different judgement task, distance effects were controlled, such that the requirement to make left and right handed responses was not conflated with the size of the magnitude judgement. Stated more concretely, small magnitude differences (i.e., 1 2), which take longer to judge compared to larger magnitude differences (i.e., 1 9) , were responded to equally often with the left hand and the right hand (see Aschcraft, 1992, Dehaene, 1989 for reviews of the robustness of the distance effect).

Relating The Sources of Evidence for the SNARC Effect from Different Tasks

Considering the results from the parity judgement, numeric comparison, and same-different judgement tasks, it is important to note that the evidence for the SNARC in Dehaene and Akhavein's same-different judgement study differs from the evidence used to argue for a SNARC effect in the parity and numeral comparison tasks described above. In both the parity and numeric comparison studies, faster left-sided responses for small single digit numerals compared to faster right-sided responses for larger numerals was taken as evidence for the SNARC effect. In these tasks the SNARC effect is the association between side of response and number magnitude. In Dehaene and Akhavein's study, faster responses to left-right oriented numeral pairs,(i.e., 1 8) compared to right-left pairs, (i.e., 8 1) were taken as evidence for the SNARC effect. In this study the SNARC effect arises from the congruence between the left-right spatial orientation of the stimulus and the orientation of the analogical mental number line. Both lines of evidence make different aspects of the SNARC effect salient.

The parity judgement and numeric comparison tasks emphasise the left-to-right directionality of the number line, with small numerals on the left and large numerals on the right. The same-different judgement task more directly assesses the analogical nature of the number line since when there is a congruence between the orientation of the physical stimulus and the mental orientation of the number line, faster responding results compared to when there is an incongruence. Both these tasks reveal related aspects of the SNARC effect. To assess the generalisablity of these results in a non-bimanual task, a same-different judgement task which requires participants to verbally respond to the target will be conducted in the current investigation. Although hand of response has been counterbalanced in these experiments it remains important to assess the SNARC effect in oral tasks because one could argue that the lateral position of the hands creates a physical continuum that emphasises spatial processing. In the current investigation an oral version of Dehaene and Akhavein's bimanual same-different task will be used to address this possibility. Other reasons for using the oral version are given in the next section.

Chapter 3: SNARC Studies and the Influence of Directionality of Writing

The only known research which studies the origin of the SNARC effect was conducted by Dehaene, Bossini, and Giraux (1993). In study 7 from this report, a parity judgement task was used to investigate number conceptualisation in French Monoliterates and in Persian-French Biliterates from Iran whose native language was Persian and whose second language was French. Persian, like Arabic, is written from right-to-left. The Biliterate participants of this study, twenty in total, had varying levels of bilingual fluency as assessed by date of immigration to France and age of second language acquisition.

The same parity judgement task described above was employed in this study. Participants pressed one response key if the target numeral was even and another response key if the target was odd. In one block of trials East-Arabic numerals (i.e., ۱,۲,۸,۹) used in the Persian langauge were presented and in a second block of trials International Arabic numerals were presented. The assignment of "even" and "odd" responses was counterbalanced with left and right handed responses to control for handedness effects.

Looking first at the overall results, where numeral type and hand of response were treated as within-subjects factors, the SNARC effect was weaker for the Biliterates than the effect in the French monoliterate group; however, it was not reversed as predicted. Since it was difficult to draw strong conclusions from a weakened effect, Dehaene et al. conducted further analyses to determine whether skill in the right-to-left writing system influenced the SNARC effect. Due to considerable individual differences in the size and direction of the SNARC effect, a second analysis was conducted to assess whether age of second language acquisition, years lapsed since arrival in France from Iran, and self ratings of Persian language skill predicted the strength of the SNARC effect. The dependent variable in this analysis was the difference between the time it took to make a left-right and a right-left judgement for East Arabic numerals. A separate analysis was conducted for International Arabic numerals. The slope of the regression was taken as a measure of the direction and magnitude of the SNARC effect, with a positive slope indicating that smaller numbers were associated with the left side of space (SNARC effect), and a negative slope indicated the Reverse SNARC. For East Arabic numerals, the only significant effect was that of number of years elapsed since arrival to France. The results showed that participants who had spent a shorter time away from Iran showed a weaker SNARC effect for East Arabic numerals. That is, participants with fewer years in a French literate environment have less of a left-to-right bias. For International Arabic numerals, age of French language acquisition predicted a stronger SNARC effect; participants who learned French earlier had stronger SNARC effects than those who learned French later in life. These findings demonstrate that individuals who use both a left-right and a right-left writing system, will show a weaker but not completely reversed left-right SNARC effect and this effect was predicted by various measures of second language skill. More broadly, the results from this study show that the degree of skill with the left-right and the right-left writing system affects the directionality of the internal mental number line.

Off-Line Influences of Directionality of Writing on Non-Numerical Processes

Dehaene et al. (1993) cite research which reveals the influence of the directionality of writing on non-numerical cognitive tasks, suggesting, as the SNARC studies show, that directionality of writing demarcates a spatial dimension which provides a fairly general means of organising information. In three separate studies, young Arabic speakers, those who used a right-to-left writing system, showed three types of right-to-left biases compared to the left-to-right biases found among English speakers. In perceptual exploration and object naming tasks Arabic readers in grade school searched object arrays and named objects from right to left while English readers searched and named from left to right (Elkind, 1969; Elkind & Weiss, 1967; Nachshon, 1985; Kugelmass & Lieblich, 1979). These biases are also revealed in graphic reproduction tasks; Arabic grade school children copy symmetrical geometrical forms and horizontal lines from right-to-left, whereas English readers copy from left-to-right (Goodnow, 1977; Goodnow, Friedman, Bernbaum, & Lehman, 1973; Lieblich, Ninio, & Kugelmass, 1975). Finally, these biases were also observed in tasks where children were instructed to organise pictures of temporally successive events (i.e., pictures that depicted events of a bedtime routine (Tversky, Kugelmass, & Winter, 1991). These findings suggest that directionality of writing is related to a wide range of non-numeric cognitive processes. Dehaene's research shows that one of these domains is number conceptualisation. Next, I go on to review evidence which shows the influences of directionality of writing on number conceptualisation.

Introduction to Oral Numeral Only SNARC Studies

Studies 1a, 1b, and 1c

Dehaene et al.'s (1993) findings suggest that the directionality of writing has an influence on how numbers are mapped onto a horizonal number line. However, data from a monoliterate group who write and read from right-to-left is required before we can make stronger claims about the influence of writing on the SNARC effect. Data from biliterate groups who use both the right-to-left and the left-to-right writing systems is meaningful only if it is compared to a monoliterate groups who use one or the other writing system. In the current study the SNARC effect will be investigated for the first time in Arabic Monoliterates who read and write only from right-to-left. If the SNARC effect is caused by directionality of writing, then we would expect a Reverse SNARC in the Arabic Monoliterate groups such that smaller numbers will be associated with the right side of a number line and large numbers will be associated with the left side. To ensure the comparability of the current findings to those of Dehaene et al., an Arabic-English Biliterate group, similar to Dehaene et al.'s Persian-French Biliterates, will also be assessed. The control group will be an English Monoliterate group which is comparable to Dehaene et al.'s French Monoliterate group. In addition to investigating the SNARC in these three literate groups, it will be investigated for the first time in a Lebanese illiterate group. Illiterates, who can read numerals only, will be studied to assess whether reading and writing practices per se, as opposed to simply living in a literate culture without having literacy skills, lead to the development of spatialised number concepts. Based on Dehaene et al.'s study, it will be hypothesised that the illiterate groups should not show either a SNARC or a Reverse SNARC effect. Finally, to investigate how level of language skill influences the spatialisation of number concepts, the SNARC effect was investigated in a small sample of Arabic-English biliterate children, herein referred to as the Child Biliterate group. The Child Biliterates read and write Arabic fluently, however their English language skills are much weaker.

In the current study, the SNARC effect will be investigated using an oral version of Dehaene and Akhavein's (1995) same-different judgement task and not the task used by Dehaene et al. (1993). There are several reasons why Dehaene et al.'s bimanual parity judgement task was not used to assess the SNARC effect in our current groups. First, the requirement to make parity judgements would be a difficult and an unnatural task for the Arabic speaking participants who have never participated in psychological experiments. More importantly it would be a difficult if not impossible task for Illiterate Lebanese speakers who recognise numerals but have little or no knowledge of parity. Second, the stimuli for the parity judgement task included number word stimuli which the Illiterate group could not read. Third, the requirement to make a bimanual response would have required speeded fine motor control. This is yet another novel task demand that requires more effort than speeded oral responses. All of these factors, which make the task increasingly novel and may create task demands that may make it difficult to interpret the findings, lead to the decision to use a different task. The task used in the current investigation was an oral version of Dehaene and Akhavein's (1995) same-different judgement task, herein referred to as the Oral Numeral Only SNARC task. The oral version of the task, in addition to avoiding the task demands discussed here, had the added advantage of assessing, for the first time, whether the SNARC effect is observable in tasks that do not require bimanual responses.

Method for Oral Numeral Only SNARC Study

Studies 1a, 1b, and 1c

Lebanese participants

Four groups of Lebanese participants were administered the Oral Numeral Only SNARC task: Arabic Monoliterates, Arabic-English Biliterates, Illiterates, and Child Arabic-English Biliterates.The Lebanese participants were individuals that I had daily contact with during my 4 month stay in two villages in the Bekka and in the Southern region of Lebanon. Most were extended family members, and friends of family members who volunteered to participate because they had time on their hands and because they felt socially obligated to me or to the person that recruited them. Most were happy to participate because they felt they were helping me with my studies. It is interesting to note the way the participants construed the experiment because it may be related to their willingness to participate. Many believed that I was secretly assessing their intelligence or speed of wit. They often felt very embarrassed when they made mistakes and some requested that I start the task again so that they could get a perfect score. An intelligence test construal of the task was common to all participant groups. Next, I describe each group separately.

The Arabic Monoliterate group consisted of 10 female and 9 male literate Arabic speakers, residing in Lebanon. They mostly had high-school and occasionally university levels of education which did not involve acquiring bilingualism in French or English. Their ages ranged from 27-45. These participants were mostly educated in Lebanese state-run village schools which, in addition to Arabic literacy, provided minimal levels of French, and in some cases, English as a second language instruction. Some of the participants recognized letters in the French-English alphabet, and could read labels and signs with some effort. However, they could not read text, or write in French or English. Work related and leisure literacy practices were performed in Arabic.

The way in which this group and the remaining groups were recruited will be described later in the procedures section where there is the opportunity to elaborate more fully on how the recruitment affected procedures for each group.

The Arabic-English/Arabic-French Biliterate group, herein referred to as the Adult Biliterate group, consisted of 17 high-school and university educated individuals. There were 13 females and 4 males, each of whom had received at least high-school levels of Arabic and French or Arabic and English language instruction in Lebanese state-run schools. Their ages ranged from 15-59. Their French or English language skills were strongly linked to school literacy practices. Second language reading and writing was not required in their work settings, and leisure reading and writing was done in their native language.

The third group assessed in the Oral Numeral Only SNARC study were eleven functionally illiterate Lebanese women, ranging in ages from 25-62, who could recognise East-Arabic numerals but could not read written Arabic text. None of these women received any formal education. Notably, there were no men participants in this group. One reason for this is that there are many fewer illiterate men, since there is a very strong emphasis on acquiring at least minimal levels of quaranic literacy, which was not emphasised for women of their generation. There may have been social reasons why illiterate men did not want to participate. However, since I had little contact with them I can not speculate about why they refused to participate.The illiterate group, in comparison to the Monoliterate and Biliterate groups, were more hesitant and somewhat suspicious of my intentions. When I asked them to participate, all but one said that they were not schooled and therefore could not do the task. However, when I modeled the task for them, they saw how easy it was and all but two agreed to participate.

The fourth group assessed in the Oral Numeral Only SNARC study was the Arabic-English Biliterate Children, herein referred to as the Child Biliterate group. The eight children that participated in this study ranged in ages from eight to 12 years. These children spoke Arabic as their native language and learned Arabic literacy as their primary language in school. They attended private Western-style schools which provided daily formal English as a second language instruction, and maths and science instruction in English. In the mathematics classroom, International Arabic rather than East Arabic numerals were used. The language skills of the Child Biliterate group, like those of the Adult Biliterate group, are primarily school based. They were not observed reading and writing at home in their second langauge. The parents of these children were members of our Arabic Monoliterate group.

Euro-Canadian Participants

There were three separate English Monoliterate groups, all of whom were recruited from the University of Western Ontario subject pool. The first group of 19 subjects, 12 females and 7 males ranging in ages from 18-43, participated in the Oral Numeral Only SNARC study. The second group of English Monoliterates, consisted of five females and 15 males ranging in ages from 18-23. For purposes of replicating Dehaene and Akhavein's study, all participants in the current study were right handed. They were administered the Dehaene and Akhavein Bimanual Replication task. The third group, which consisted of 9 right handed females and 11 right handed males ranging in age from 19-23, was administered the Oral Version of the Dehaene and Akhavein Replication task.

Apparatus

A MacIntosh Powerbook G3 laptop with a 14" Colour Liquid Crystal Display Monitor was used to present the stimuli. A MacIntosh Simple Talk external microphone connected directly into the computer was mounted on the right side of the screen. The application program Superlab (version 1.74; Cedrus Corporation) was used to display stimuli and to record and time participants responses to the nearest millisecond. Stimulus presentation could not be synchronised with the refresh rate due to the properties of liquid computer displays on all laptop computers. The asynchrony between stimulus presentation and refresh rates is an unavoidable source of error variability in the reaction times. An estimate of the size of this variability could not be obtained for LCD monitors. However for standard monitors the variability is 15 milliseconds.

Materials

Participants in the Oral Numeral Only SNARC task were presented with two black numerals in 72 point font simultaneously on a white 14" computer screen. One numeral appeared 35 mm to the left of the centre and the other numeral appeared 35 mm to the right of the centre of the screen. The English Monoliterate groups were presented with different combinations of International Arabic numeral pairs made up of the following set of numerals used in Dehaene and Akhavein's (1995) original study: 1, 2, 8, 9. The Arabic Monoliterate, Adult Arabic-English/French Biliterate, Illiterate, and Biliterate Child groups, were presented with the identical set of East Arabic numerals (i.e., ١,٢,٨,٩).The participant's task was to respond "yes" into a microphone if the numerical pairs had the same numerical values, and "no" if they had different values. The numeral disappeared at the onset of a response, consequently the length of time the stimulus was presented was not held constant for each trial across participants. The interstimulus interval, the length of time between the verbal response and the presentation of a new trial, was 1000 msec. Reaction time latencies were recorded within 1 msec accuracy.

The participants were presented with five types of stimulus pairs varied systematically on two variables, numerical disparity, and spatial orientation. There were three levels of numerical disparity: equal numeral pairs (i.e., 1 1), close pairs that differed by one value (i.e., 1 2), and far pairs that differed by six or more values (i.e., 1 9; 2 8). The close trials are filler trials and were not included in the statistical analyses. The numeral pairs of interest in our SNARC studies were the two left-right and right-left far trials, since all previous studies have observed the SNARC effect on far trials only (Brysbaret, 1995; Dehaene and Akhavein, 1995; Dehaene, Bossini, Giraux, 1993; Dehaene, Dupoux, and Mehler, 1990). The close trials, which reliably take longer to judge, were included to create some variability in the decision making process and to ensure that judgements were grounded in semantic processing as opposed to perceptually based judgements (Dehaene & Akhavein, 1995; Dehaene et al. 1993; Dehaene & Changeux, 1993; Gallistel & Gelman, 1992; Moyer & Landauer, 1967). The close and far trials were also varied by spatial orientation; for the left-right orientation the smaller numeral was on the left (1 2; 2 9), and for the right-left orientation the smaller numeral was on the right (2 1; 9 2). In total there were five numeral pair types: 1) equal, close left-right, close right-left, far left-right, and far right-left pairs.

Participants made "same-different" numerical judgements for 96 randomised trials, 48 equal trials and 48 different trials. Within the different trials they received 16 left-right far trials, 16 right-left far trials, 8 left-right close trials, 8 right-left close trials. The total number of trials was limited to 96. Moreover, it is important to note that Dehaene and Akhavein (1995) did not include an equal number of same and different trials. This methodological difficulty, which arguably creates biases in the decision making processes and potentially changes how the stimulus is being processed, was corrected in the current investigation. Consequently, participants made the same number of "yes" and "no" judgements, in accordance with the accepted convention in reaction time studies.

General Procedure for All Groups

In the Oral Numeral Only task, all participants were seated in front of a laptop computer which had a MacIntosh Simple Talk microphone mounted to the right side of the screen. All participants were instructed to say "yes" in their native language if the stimulus pairs had the same numerical value and "no" when they had different values. The words for "yes" and "no" in Arabic are monosyllabic words and thus the articulatory processes involved in making a response in Arabic could be directly compared to English responses. In the instructions to the participants, it was emphasised that they should answer as quickly as possible and avoid making any mistakes. Moreover, they were instructed to continue without stopping if they made mistakes. The procedures for the Lebanese and the English Monoliterate groups will be described separately since the setting of the experiments and the participants' level of experience with psychological experimentation required modifications to conventional laboratory procedures.

Procedure for Lebanese participants. The participants in the four Lebanese groups were administered the tasks in their homes, work places, or other convenient non-laboratory settings. I will describe the conditions under which the studies were conducted in the field since they differed in some notable ways from the laboratory conditions under which the English Monoliterate groups were tested. In doing so, I will describe the ways in which the experiments were conducted, and the strategies I used to met the demands of cross-cultural fieldwork with "naive" participants. The ways in which these field experiments were conducted permitted meaningful and valid comparisons between the Lebanese groups and the English Monoliterate groups who were familiar with the socially situated practice of psychological experimentation. The pre-experimental interview, the processes of training the participants, as well as the conditions under which the studies were conducted will be described next.

Before conducting the test phase of the study, each participant was asked the following questions about their level of schooling and their language skills:

1) which school did you attend and what was the highest grade you finished?

2) what languages did you learn in school, and how many hours did you spend each week in second language classes?

3) does your work require second language skills?

4) do you read for leisure in your second language?

Upon completion of this short interview, the computer was prepared for the experiment. Very few of the participants, even the bilingual participants who were still attending school, used computers on a daily basis, and thus the notion of being tested on a computer appeared to be disconcerting. To ease some of their anxieties about the computer, I talked about the practical things laptops can be used for while I was setting up the microphone and loading the programs. Getting international radio broadcasts off the internet was a topic of interest. They also found the graphics programs interesting. If I still felt they were overly anxious, I modelled the task for them. I did this for all the illiterate participants, and some of the Arabic Monoliterate participants. Once they saw how mundane the task was their apprehensions eased.

During the training phase of the experiment, participants were given a number of practice trials to get them accustomed to the many peculiar aspects of reaction time studies that make them very much unlike everyday numerical tasks such as: 1) the repetitious nature of the trials, 2) the requirement for highly speeded responses upon the presentation of the stimulus, 3) the requirement for sustained and highly focused attention, 4) the requirement to interface with computer equipment which involves: a) knowledge about the sensitivity of the microphone, b) the requirement to respond clearly with the words "yes" and "no" and no other words or sounds, c) experience with the time intervals between the onset of a stimulus, their verbal responses, and the presentation of a new stimulus. I also gave the participants enough trials to observe them making errors. Many of the participants became quite flustered after they made errors during the training phase. At times they missed 2-3 trials as they made comments or gestures about their mistakes even though instructions emphasised they should continue without hesitation. Nevertheless, when mistakes were made during the training phase, Lebanese participants took more time to refocus on the trials than did the experienced Euro-Canadian participants. Many of these difficulties were corrected during the training phase and when they occasionally arose during the testing phase, the interruption was noted and the corresponding trials were removed from the subject's data set, and recorded as a non-trial. Appendix A provides a breakdown of the number of non-trials for each group, as well as outlier trials and errors. A trial was considered an outlier, if it varied three or more standard deviations from the mean of all the response times A trial was considered an error when the participant gave an incorrect response. The high rate of non-trials is attributable to the less-than-ideal settings in which the experiments were conducted.

Turning to the test phase of the study, I attempted as much as possible to conduct the experiments in quiet settings, but testing sessions were most typically noisy and on several occasions they were interrupted. I will describe the conditions of testing in some detail to portray a realistic picture of how field experimentation differs from laboratory experimentation.

Most of the testing sessions were conducted in the homes or work places of the particpants, and on one occasion the testing session was conducted in a roomy blue-grey Mercedes, for lack of a quiet place. Also on occasion, some participants came in small groups to my home to be tested. It was only on rare occasions that participants were tested by themselves without onlookers. More typically other participants sat in on the testing session. At first, when I was naive about the practical difficulties of experimentation in the field and when I was excessively eager to recreate a laboratory setting, I tested the participants in a different room from the onlookers. However, since it wasn't socially appropriate for a young woman and a man to be together in a room alone, I resorted to testing each participant in the presence of family members and other interested people. These public testing sessions turned out to be advantageous in a number of respects even though there was the potential for distraction. I realised that participants learned a lot about how to do the experiment and felt more at ease after they had watched their peers. Furthermore, these public testing sessions encouraged participants to respond quickly to the stimulus since they thought their results were going to be individually and publicly compared to the results of others.

There were two sources of noise that distracted some of the participants during testing. These distractions lead to missed trials, which were more frequent in the field setting compared to the very low number of missed trials in the laboratory setting (see Appendix A for a breakdown of the number of non-trials for each group). Outside noise or noise from another room in the house was one source of distraction, and when it was very loud and abrupt, it triggered the microphone before the participant responded. In such cases, the 3 trials after the onset of the interruption were treated as non-trials. The other source of distraction was people. Since the testing was often done in groups, and since family members and close neighbours came in and out of each other's houses and businesses freely, there were several occasions when the testing session was interrupted to varying degrees. When the interruption was long, I stopped the testing session and continued it later or on another day depending on the circumstances of the interruption and the participant's willingness to start again. If the interruption caused the participant to momentarily look away from the screen, the three trials that followed the interruption were excluded from the analysis. If the interruption did not cause the participant to look away or visibly hesitate in their response, the interruption was noted but the trials were included in the data set. I attempted to minimise these interruptions by arranging testing sessions at times when participants were alone at home, but this was not possible in many cases. The testing conditions described here unavoidably lead to a high level of random error variance which should not be correlated in any systematic way with the effects being observed. Consequently, if the directionality of writing influences number conceptualisation, the effect would have to be very robust to outweigh error variance caused by the testing conditions.

Procedure for English Monoliterate participants. All participants from the English Monoliterate group were administered the task individually in a quiet lab environment. The English Monoliterate group received 10 practice trials before they received the 96 test trials. Instructions to the participants encouraged them to respond as quickly as possible and not make mistakes. The experiment took 5-8 minutes in total, and participants received credit for their participation.

Results Study 1a

Oral Numeral Only SNARC Study with Arabic Monoliterates, Arabic-French/Arabic English Biliterates, and English Monoliterates

The analysis of variance conducted to assess the SNARC effect in the Arabic Monoliterate, Adult Biliterate, and English Monoliterate groups involved a between-subjects factor (the three participant groups) and one within-subjects factor (left-right numeral pairs versus right-left numeral pairs).

A 2 x 3 analysis of variance was conducted to investigate whether the speed of right-left and left-right judgements was affected by directionality of writing practiced by the three groups. Results, shown in Table 1, reveal a significant interaction between group and the directionality of the numeral pairs, $F(2, 50) = 3.17$, $p = .044$.

Table 1

<u>Oral Numeral Only SNARC Study: The mean length of time in milliseconds it took Arabic Monoliterates, Arabic-English Biliterates, English Monoliterates, Lebanese Illiterates, and Child Biliterates to make left-right and right-left numerical judgements</u>

Groups	Mean Raw Scores left-right (i.e., 1 9)	right-left (i.e., 9 1)	Difference Score
Arabic Monoliterates (n=19)	812 (106)	785 (112.)*	27
Arabic-French English Biliterates (n=17)	755 (126)	740 (125)	15
English Monoliterate (n=19)	764 (128)	775 (138)	-11
Illiterate (n=11)	926 (72)	910 (75)	16
Biliterate Child (n=8)	1080 (158)	1028 (194)*	52

* significant difference (p < .05) between left-right and right-left responses, as assessed by posthoc tests

In this analysis only the interaction between the left-right/right-left pairs and group was of theoretical significance. The main effect for the left-right/right-left factor and the main effect of group were not significant, and will not be discussed since they are not of theoretical significance. However, for a summary of the analyses of variance results see Appendix B.

To determine which groups showed a SNARC or a Reverse SNARC effect, simple main effect posthoc tests were conducted. The Arabic Monoliterate group showed a Reverse SNARC. They responded 27 msec faster to numerals oriented from right-left compared to left-right numeral pairs. This difference was significant, $Q\,(2{,}50) = 3.55$, $p < .05$. Arabic-French/Arabic-English Biliterates showed a non-significant trend towards a Reverse SNARC, which will be discussed shortly. They judged right-left numeral pairs 15 msec faster than left-right pairs, however, this difference was not significant, $Q\,(2{,}50) = 1.953$, n.s. Finally, the English Monoliterate group showed a non-significant trend towards the SNARC effect, because left-right judgements were slightly faster (11 msec) than right-left judgements, $Q\,(2{,}50) = 1.487$, n.s. The finding of no SNARC in the English monoliterate group is contrary to Dehaene's findings which show a significant SNARC in French and English monoliterates in bimanual parity and same-different judgement tasks.

To assess which groups differed significantly with respect to the size of the Reverse SNARC effect, three independent one-tailed t-tests were conducted comparing the size of the effect in the three groups. The dependent variable for the t-test was the difference in the time it took to make a left-right response compared to the time it took to make a right-left response. A positive difference score indicated a Reverse SNARC and a negative score indicated a SNARC effect. Looking at the Arabic Monoliterate group and the English Monoliterate group, the Arabic group showed a significantly stronger Reverse SNARC ($\underline{M}$ = 27), compared to the SNARC trend of the English group ($\underline{M}$ = -11), $\underline{t}$ (36) = 2.11, $\underline{p}$ < .05. Comparing the Arabic Monoliterate group and the Biliterate group, the Monoliterate group ($\underline{M}$ =27) did not show a significantly stronger Reverse SNARC compared to the Biliterate group ($\underline{M}$ = 15), $\underline{t}$ (34) = 0.76, $\underline{p}$ > .05. Finally, the trend towards a Reverse SNARC in the Biliterate group was significantly different from the trend towards a SNARC in the English Monoliterate group, $\underline{t}$ (34) = 1.70, $\underline{p}$ < .05. This finding clearly shows, for the first time, that the right-to-left writing system is related to the directionality of the SNARC effect.

Study 1b

Illiterate Oral Numeral Only SNARC study

A small group of Illiterate Lebanese women participants who could read numerals but not written words, were administered the Oral Numeral Only task. No SNARC effect or Reverse SNARC was observed. Right-left numeral pairs were not judged significantly faster than left-right pairs, $\underline{t}$(10) = 1.02, $\underline{p}$ > .05 (see table 1 for the means). Because no SNARC effect was observed in the illiterate group, this result supports the theoretically motivated hypothesis that writing gives rise to the spatialisation of number concepts.

Study 1c

Biliterate Child Oral Numeral Only SNARC study

The Arabic-English biliterate children were given the Oral Numeral Only SNARC task. Results of a paired t-test showed a significant Reverse SNARC where right-left numeral pairs were judged 52 msec faster than left-right pairs, $t(7) = -2.68$, $p < .05$

(see table 1 for the means). This was similar to the results of the Monoliterate Adults of Study 1a, however, the size of the effect was much larger, 52 msec compared to 27

msec. For Biliterate Child the effect was 52 msec compared to a 27 msec effect for the Adult Monoliterate group and the 15 msec effect in the Adult Biliterate group.

Discussion

Study 1a, 1b, and 1c

Results of the Oral Numeral Only SNARC study show, for the first time, clear support for the hypothesis that the directionality of one's writing system has an effect on number conceptualisation. In the Arabic Monoliterate group, reading and writing from right-to-left gives rise to a Reverse SNARC, while this effect was not significant in either the Adult Arabic-English/French Biliterate group or in the English Monoliterate group. The non-significant trend towards the Reverse SNARC in the Adult Biliterate group suggests that the strength of the Reverse SNARC effect is weakened by the influences of a left-to-right writing system in French or English but not completely reversed. These results parallel those found in Dehaene et al.'s (1993) study in which highly skilled Persian-

French biliterates did not show a significant SNARC effect compared to French monoliterates. The main difference, however, between the present Arabic Biliterate group and Dehaene's Persian-French Biliterate group is the direction of the trend. For the Arabic Biliterate group, influences of the left-right writing system weaken the Reverse SNARC, while in the Persian-French biliterate group, the weakened trend is towards the SNARC effect. Thus it seems that although the participants' native right-to-left writing system still has influence over how numbers are conceptualised, even for the Persian-French biliterates who have acquired university level French language skills, one's level of skill with the left-to-right writing system has an effect on the size of the SNARC effect or the size of the Reverse SNARC. The results of Dehaene et al.'s regression analysis further suggest this. The regression analysis showed that the strength of the trend towards that SNARC effect varied with second language skill, as assessed by the length of time an individual was away from Iran, such that participants who had spent more time in France showed a stronger trend towards a SNARC effect, and those that spent less time in France showed a weaker SNARC trend.

Taking the current results from the Adult Biliterate group and Dehaene et al.'s basic finding and subsequent regression analysis, it seems that the influences of the native language become weaker only as the influences of the second language become stronger. Results from the Child Biliterate group, which show a strong Reverse SNARC further suggest that second language skill, which is just beginning to develop in these children, is not sufficiently strong to weaken the Reverse SNARC effect caused by the influences of the Arabic right-to-left writing system.

Results from the illiterate group which do not show a significant Reverse SNARC further support the view that the spatialisation of number concepts is influenced by reading and writing practices. Results from the illiterate group cannot be compared to the trend towards a Reverse SNARC in the Adult Biliterate group since the overall response times for Illiterates was 170.5 msec slower than the Adult Biliterate response times. This difference in speed of responding and the fact there are no previous findings which compare the size of the Reverse SNARC effect in biliterates and illiterates limits us in making meaningful effect size comparisons.

It is possible, however, to consider how the strength of the Reverse SNARC varied for the Arabic Monoliterate group and the adult Biliterate group, since there is evidence from Dehaene et al. which shows that the size of the SNARC effect varies with level of second language skill. Results of the independent t-test reported above did not reveal that the trend towards a Reverse SNARC in the Adult Biliterate group was significantly weaker than the significant Reverse SNARC effect in the Arabic Monoliterate group. Although these results are in the predicted direction, consideration will be given to why this trend may not have reached statistical significance. The level of second language skill in the Adult Biliterate group was not high, since 15 of the 17 participants of the current study had only high-school levels of English as a second language and French as a second language instruction. Further evidence that their second language skills were limited was that the same 15 participants no longer practiced their second language, nor were employed in jobs that required French or English langauge skills. Moreover, none of the 17 participants reported that they read for leisure in their second language and all reported that second language reading and writing was limited to school subject matter. From these observations, it will be concluded that second language skill in the Arabic Biliterate group was not comparable to the more fluent French language skills of most of Dehaene et al.'s Persian-French biliterates. As a follow-up to the current study, research is required that looks at the relationship between level of second language skill and strength of the Reverse SNARC. It was not possible to run such an analysis with the data from the Adult Biliterate group since there was a restricted range of variability in second language skills. Future research will require a larger sample of highly skilled and minimally skilled Arabic-English biliterates to study the influences of left-to-right literacy skills on the strength of the Reverse SNARC effect.

Turning to the English Monoliterate group and their performance in the Oral Numeral Only task, the most surprising finding was the lack of significant trend towards the SNARC effect. This finding contradicts the findings from the parity judgement and numerical comparison tasks, and the one other same-different judgement task (Dehaene & Akhavein, 1995), all of which showed a significant SNARC effect for French and English Monoliterate participants. Most notably, the SNARC effect was observed in Dehaene and Akhavein's (1995) study which employed a same-different judgement task. Dehaene and Akhavein's task differed from the Oral Numeral Only SNARC task employed here in two ways. First, recall that the stimulus pairs in Dehaene and Akhavein's study included different combinations of number words and numerals, whereas the stimulus here included only numeral-numeral pairs. Second, Dehaene and Akhavein employed a bimanual task where the current task required participants to orally respond to the target stimuli. Furthermore, handedness could also be influencing performance or interacting in some way with the processing of the spatialised visual display. Although Dehaene and Akhavein counterbalanced hand of response with side of response, as described above, they did not statistically assess whether the SNARC effect was stronger for right handed responses compared to left-handed responses. Comparing Dehaene and Akhavein's result with the result of the Oral Numeral Only study, it is not possible to determine whether the non-significant SNARC effect observed in the current study with English Monoliterates was due to one or more of these influences. Before more careful consideration is given to how these variables may affect the strength of the SNARC effect, the results from a task identical to the bimanual same-different judgement task used in Dehaene and Akhavein's (1995) study will be reported. In this task, 20 English Monoliterates were tested to determine whether Dehaene and Akhavein's results are replicable. The method for this study which has been termed Dehaene and Akhavein's Bimanual Replication Study will be described next.

Method for the Replication of Dehaene and Akhavein's (1995) Bimanual Study

Study 1d

Apparatus

A MacIntosh Powerbook G3 laptop was used to present the stimuli. The computer was interfaced with a model MK6 Button box, developed by MacWhinney, Laxman, and Taylor. The application program PsyScope (version

1.02, Cohen, MacWhinney, Flatt, & Provost, 1993) was used to present, time, and record the responses to the nearest millisecond.

Materials

In the replication study, which assessed English Monoliterates, combinations of numeral and number word pairs were presented on a laptop computer screen. In the first block of trials the participant's task was to press the left key if the numbers represented the same quantity and right key if they represented different quantities. This key assignment was reversed for the second block of trials, and the order of the two blocks was counterbalanced.

Participants were presented with stimulus pairs that varied on three variables; disparity, left-right vs. right-left orientation, and notation. The first two variables are identical to those used in the Verbal Numeral Only study. The third variable identifies four types of word and numeral notation pairs: 1) Number word-Number word pairs (one nine, nine one), 2) Number word-Numeral pairs (one 9), 3) Numeral-Number Word (9 one), and 4) Numeral-Numeral (9 1). Considering all three variables, the test trials consisted of 20 different stimulus pairs. For example, the Number Word-Numeral will have the following stimulus types: same (eight 8), left-right far (one 9), right-left far (nine 1), left-right close (one 2), and right-left close (nine 8). These five types were repeated for the Number Word-Number Word, Numeral-Number Word, and Numeral-Numeral pairs, for a total of 20 types of stimulus pairs. Within each stimulus type there were 16 same pairs, 16 left-right far pairs, 16 right-left far pairs, 8 left-right close pairs, and 8 right-left close pairs, for a total of 256 trials across all stimulus types. Participants received 256 randomised trials in the first block and a newly randomised set of 256 randomised trials in the second block. It is important to note that one-third of the trials in this task were "yes" trials and two-thirds were "no" trials. Although, the unequal proportion of yes/no trials allows for a higher level of guessing and potentially biases subjects to make more perceptually based judgements, we followed Dehaene and Akhavein's original study to see if their results were replicable.

Procedure

In the Bimanual Replication study, participants were seated approximately 50 cm from the computer screen. They were instructed to press one key if the stimulus pairs had the same numerical value (i.e., one 1) and another key if they had different values (i.e., 1 8). In the first block of 256 trials, the "same" responses were assigned to the left hand and the "different" responses were assigned to the right hand. This assignment was reversed in the second block, and the order of the blocks was counterbalanced across participants. In the instructions to the participants, it was emphasised that both speed and accuracy were equally important.

Results and Discussion Study 1d

Replication of Dehaene and Akhavein's Bimanual SNARC study: Bimanual Number Word and Numeral SNARC Study with Right Handed English Monoliterates

In the Bimanual Number Word and Numeral SNARC task, I studied whether the time it took to make a difference judgement was affected by left-right compared to right-left orientation of stimulus pair (left-right/right-left factor), the presence of number word and numeral combinations (notation factor), and the hand in which the difference judgement was made (hand of response). A 2x4x2 repeated measures analysis of variance was conducted to assess these effects in an English Monoliterate group.

Left and right handed responses and the SNARC effect. The only significant main effect observed was for the notation factor, $F(3,64) = 64.06$, $p < .001$ (see Appendix C for a summary of the analysis of variance results for all factors). Results of a Tukey HSD post hoc analysis show that the numeral-numeral pairs, collapsing across hand use and left-right/right-left factor, were judged faster ($M = 363$) than numeral word-numeral pairs ($M = 432$), $Q(3,57) = 7.41$, $p < .01$, and faster than numeral-numeral word pairs, ($M = 446$), $Q(3,57) = 8.97$, $p < .01$ and numeral word-numeral word pairs, ($M = 429$), $Q(3,57) = 7.12$, $p < .01$. It is likely that numeral-numeral pairs can be judged quickly by means of perceptual similarity, faster than the other three notation conditions that require word reading. This main effect is not theoretically meaningful and will not be discussed further. The primary main effect of interest, for the left-right/right-left factor, showed a non-significant trend towards the SNARC effect, $F(1,19) = 2.893$, $p = .10$. Thus the current results, while in the same direction, do not replicate those from Dehaene & Akhavein which showed a significant SNARC effect.

Referring to Table 2, the trends in the means indicate that the strongest SNARC effect was observed in the number word-numeral condition when participants responded with their right hand only.

Table 2

Bimanual Replication SNARC study: Mean length of time in milliseconds it takes Right Handed English Monoliterates to make left-right and right-left numerical difference judgement with their right and left hands when presented with four types of number pairs: number word-numeral, number word-number word, numeral-numeral, and numeral-number word

	Difference Judgement with Right Hand		
	Left-right	Right-left	Difference Score
Number word-Number word	441 (87)	449 (82)	-8
Number word-Numeral	418 (68)	442 (89)*	-24*
Numeral-Number word	424(65)	427 (73)	-3
Numeral-Numeral	350 (59)	360 (69)	-10
Mean	408 (63)	419 (71)	-11

	Difference Judgement with Left Hand		
	Left-right	Right-left	Difference Score
Number word-Number word	440 (67)	456 (82)	-16
Number word-Numeral	428 (71)	438 (82)	-10
Numeral-Number word	439 (81)	427 (65)	12
Numeral-Numeral	373 (86)	372 (78)	1
Mean	420 (72)	423 (71)	-3

* significant difference ($p < .05$) between left-right and right-left responses, as assessed with simple main effect tests

Based on the trends in the means, an exploratory 2x4 repeated measures analysis of variance for right handed responses only was conducted to assess the SNARC effect when difference judgements were made with the right hand. Results revealed a significant SNARC effect with right handed responses; left-right pairs (M = 408) were judged faster than right-left pairs (M = 419), F (1,19) = 4.14, p = .05. The interaction between SNARC effect and the notation effect was not significant, F (3, 57) = 0.78, p = .541. Although the interaction was not significant, simple main effect tests were conducted to determine which notation condition was driving the SNARC effect since there was considerable variability in the size of the SNARC across the conditions (see Table 2). Results showed a significant SNARC only when participants responded with their right hand to number word-numeral pairs, Q (3, 57) =3.16, p < .01. The same analysis was conducted for left hand responses and results show no SNARC, F (1,19) = 0.45, n.s., and no SNARC by notation effect interaction, F (3,57) = 0.15, n.s (see Appendix D for a summary of the full analysis of variance).

Taking all the results of the replication study together, it can be argued that the SNARC effect for English speakers is strongest when participants are responding with their right hand and when words expressing a number appear on the left side of the screen. Left hand responding and the absence of left-right number word-numeral combinations seemed to eliminate the SNARC effect. The failure to replicate Dehaene and Akhavein's (1995) main findings which showed a SNARC effect and no SNARC by notation interaction, suggest that the SNARC effect, as it is revealed in the same-different bimanual judgement task, is unstable and possibly arises only when participants respond with their right hand and when there are words on the left side of the screen. Since Dehaene and Akhavein did not report the mean response times for left-right compared to right-left pairs across the four stimulus conditions, it is not possible to judge whether the SNARC effect was stronger in the number word-numeral condition in their study. Nevertheless, the results of the current study suggest that the presence of a number word-numeral pair is likely to call forth a left-to-right spatial framework. It is not likely that the presence of a number word per se which calls forth left-right literacy-based scanning patterns is causing the SNARC effect because the effect is not observed in number word-number word pairs. A more likely explanation is that the number word-numeral pairs may invoke a left-right spatial frame which is congruent with an internal analogical representation which is oriented from left-to-right. A left-right analogical code does not seem to be strongly activated by numeral-number word pairs nor numeral-numeral pairs, both of which did not show significant SNARC effects.

Rationale For a Follow-up Study

There were two shortcomings to Dehaene and Akhavein's bimanual same-different numeric judgement study that will be addressed and corrected in a follow-up study. Since the findings of the current study suggest that hand of response is affecting the strength of the SNARC effect, an oral version of the bimanual task was conducted. Furthermore, the same number of "yes" and "no" trials were included to avoid decision making biases which, arguably, can account for some of the instability of Dehaene and Akhavein's results. An oral Version of Dehaene and Akhavein's original bimanual task, which will be described next, was designed to assess the SNARC effect in a new English

Monoliterate group for a final time.

Method for Oral Version of Replication Study

Study 1e

Apparatus

A MacIntosh Powerbook G3 laptop interfaced with a model MK6 Button Box was used to present the stimuli . A electric condenser microphone, connected to the PsyScope button box timer, was used in the Oral Version of the Replication study. The PsyScope application program was used to present, time, and record responses to the nearest millisecond accuracy.

Materials

In the Oral Version of the Bimanual Replication Study participants were instructed to respond "yes" when stimulus pairs had the same numerical value, and "no" when they had different values. The stimuli for the Oral Version of the study were identical to the stimuli in the Bimanual Replication study except in two important ways. First, there were 384 trials overall, compared to 512, since it was not necessary to counterbalance for hand of responding. Furthermore, the proportion of "yes" and "no" trials was equal, with 192 "yes" trials and 192 "no" trials. In the first block of trials, 192 randomised trials were presented, followed by a 5 minute stretch break and then the second block of 192 trials. For each stimulus type there were 96 trials, 48 same trials and 48 different trials. The following is a break down of the different trials for one of the four stimulus types, number word-numeral pairs: 16 left-right far number word-numeral pairs, 8 left-right close number word-numeral pairs, 16 right-left far number word-numeral pairs, and 8 right-left close number word-numeral pairs. The same proportions of same and different trials were repeated for the number-word-number word, numeral-numeral, and numeral-number word stimulus types.

Procedure

The procedure for the Oral Version of the Replication study was identical to that of the Bimanual Replication study except that the particpants responded "yes", into a hand held microphone, when the numeral pairs had the same value and "no" when they had different values. Participants received 192 randomised trials in the first block followed by a short break and then another 192 randomised trials in the second block.

Results and Discussion Study 1e

Oral Version of Dehaene and Akhavein's (1995) original bimanual task

The main purpose of this study was to test whether the SNARC found in Dehaene and Akhavein's can be observed in an oral version of the task. Results of a repeated measures analysis of variance did not reveal a significant main effect for the left-right/right-left factor: left-right numeral pairs were not judged significantly faster, (M = 582, SD = 112,) than right-left numeral pairs, (M = 585, SD =114), F (1,19) = .514, n.s.(see Table 3).

Table 3

Oral Version of Replication Study: Mean length of time in milliseconds it takes English Monoliterates to make left-right and right-left numerical difference judgement with four types of number pairs: number word-numeral, number word-number word, numeral-numeral, and numeral-number word

	Left-to-right	Right-to-left	Difference Score
Number word-Number word	614 (127)	615 (126)	-1
Number word-Numeral	579 (100)	621 (119)*	-42*
Numeral-Number word	599 (118)	596 (110)	3
Numeral-Numeral	534 (104)	510 (102)	24
Mean	581 (112)	585 (114)	-4

* significant difference ($p < .05$) between left-right and right-left responses, as assessed by posthoc tests

The main effect of notation was significant, $F(3,57) = 31.98$, $p < .001$. Post hoc tests revealed the same results found in the Bimanual study; that is, numeral-numeral pairs ($M = 522$) were named faster than number word-numeral pairs ($M = 600$), $Q(3,57)= 7.503$, $p < .05$, and faster than number word-number word pairs, ($M = 614$), $Q(3,57)= 8.86$, $p < .05$, and finally, they were named faster than numeral-number word pairs, ($M = 597$), $Q(3,57)= 7.24$, $p < .05$. Turning to the interaction, the SNARC effect interacted significantly with notation, $F(3,57) = 6.32$, $p = .001$ (see Table 3). Planned simple main effect tests showed that the left-right SNARC was significant only in the number word-numeral condition: left-right number word-numeral pairs ($M = 579$, $SD = 99$) were judged faster than right-left number word-numeral pairs, ($M = 621$, $SD = 119$) $Q(1,19) = 5.68$, $p < .05$ (see Table 3 for the means for all notation conditions). The effect was not significant in the number word-number word, numeral-numeral, or the numeral-number word notation conditions. This finding is consistent with the finding from the Bimanual replication study which showed a significant SNARC only in the number word-numeral condition.

Two conclusions can be drawn from the results of the Oral Version of Dehaene and Akhavein's same-different judgement tasks. First, the SNARC effect is strongest when a number word appears on the left side of the screen in tasks that require participants to judge whether left-right compared to right-left stimulus pairs have the same or different numerical values. Second, the requirement to respond bimanually or orally does not seem to be the main factor driving the SNARC effect. However, the possibility that a bimanual mode of response, which sets up a spatialised form of responding, may interact in some way with the left-right or the right-left spatial orientation of the stimulus pairs can not be ruled out because an overall SNARC effect was not observed in the attempt to replicate Dehaene and Akhavein's bimanual study. Since the variability caused by these factors is controlled in the oral version of the task, the evidence from the oral version of the same-different judgement task will be taken as stronger evidence for the SNARC effect in English Monoliterate participants.

The results of the Oral Version of the Replication study suggest that the SNARC effect is strongest when a number word appears on the left side of the screen and a numeral appears on the right. I will argue that this happens because the visual stimulus invokes a representation which is congruent with a left-right analogical number line. I will rule out the possibility that the left-to-right visual scanning patterns involved in reading is driving the effect since number word-number word pairs show no SNARC effect; right-left pairs were responded to as fast as left-right pairs (1 msec mean difference). It is likely that number word-number word pair comparisons emphasise surface notation processing of the written word and therefore do not assess, to the same degree, the conceptually-based processes required in mixed notation comparisons. One further question remains, why is the SNARC effect observed for number word-numeral notation (one 9 vs nine 1), but not for numeral-number word notation (1 nine; 9 one)? This question did not arise in Dehaene and Akhavein's (1995) research because they found no notation effect. However, since the current findings from two separate studies show the SNARC effect only for number word-numeral pairs, I will speculate on why the SNARC is found when participants make same-different judgements with number word-numeral pairs but not numeral-number word pairs.

I will start with some known assumptions about the visual scanning patterns of literate persons. The number word and numeral pairs that appear on the screen are far enough apart (7 cm) that they cannot be apprehended in one eye fixation, consequently only one stimulus can be apprehended at a time (see Rayner, 1999 for a review of the literature on eye movements during reading). English monoliterates will read the stimulus on the left side of the screen first since they show left-right visual scanning patterns (Rayner, 1999). With these two points as background, I will argue that, there is something about the order in which number words and numerals are processed which leads to larger differences in the time it takes to make left-right compared to right-left judgements. If we follow this line of reasoning, the number word in the number word-numeral pairs is processed first. It is possible that this initial processing of a number word leads to the association between the number magnitude and the left side of the number line because words are read from left to right. In the second fixation, the magnitude code for the numeral is processed and associated with a point on the number line relative to the first number concept which has already being associated with the left side of the line. If the numeral happens to be larger in magnitude than the number word concept, than the numeral will be associated with the right side of the number line and the natural mapping between large numbers and the right side of space will not be disturbed. However, if the numeral is smaller in magnitude than the larger number word concept, the more effortful processes of placing the smaller magnitude to the right of the first magnitude for English Monoliterates slows down the decision making process. This disruption in the more natural left-right mapping processes may not arise in numeral-number word pairs because the Arabic numeral is not automatically associated with the left side of the number line. Thus, according to this interpretation, it seems that the SNARC effect is strongest when words appear on the left side of the screen, at least as it is assessed in the same-different judgement task.

Comparing the current results from the same-different judgement tasks with results from past studies using parity judgement and numerical comparison tasks, the results of both the bimanual replication study and the oral version of the study leave us with one further question: why is a significant SNARC effect observed only in the number word-numeral stimulus conditions, whereas it has been consistently observed in parity judgement and numeric comparison tasks which involve decisions about single digit Arabic numerals instead of pairs (Dehaene & Cohen, 1991; Dehaene, Bossini, & Giraux, 1993; Dehaene & Cohen, 1991; Dehaene, Dupoux, & Mehler, 1990)? An interpretation of the pattern of results from different tasks and what they reveal about the SNARC effect has not been offered by Dehaene and colleagues even though they have repeatedly noted that these results reveal different aspects and forms of the SNARC effect (Dehaene, 1992; Bachtold et al. 1998; Brysbaert, 1995; Dehaene et al., 1993). An interpretation will, however, be attempted here. It will be postulated that in the parity judgement and numeric comparison tasks, the requirement to press a left-sided key with one hand and the requirement to press a right-sided key with the other hand, invokes a spatialised number line that is linked to a bimanual mode of responding. The bimanual mode of responding makes salient the linkages between small numbers and the left side of space and large numbers and the right side of space. Turning to the same-different judgement task, the source of the SNARC effect seems different since it more directly assesses the spatial properties of the number line compared to parity judgement tasks which indirectly investigate the number line by studying the associations between small numbers and the left side of space and large numbers and the right side of space. In the bimanual parity judgement task, the number line is assessed in this rather indirect way which makes salient different aspects of the SNARC effect. The implications of the results from studies 1a, 1b, 1c, and 1d for theories of number processing will be taken up in the General Discussion.

Chapter 4: Currency Bill as Artifact in the Maths of Selling Practice

The second part of the dissertation concerns another kind of influence of artifacts on numeric cognition. In these separate series of studies, I investigated whether currency bills as artifacts in the maths of selling practice shaped bill and numeral recognition and number conceptualisation.

Studies of number representation that are based on how people comprehend and use numbers in everyday settings have emphasised how skilled practice with various physical artifacts, such as the abacus or the soroban, mediate number representation and shape arithmetical processes (Hatano, Amaiwa, & Shimizu, 1987; Hatta, Hirose, Ikeda, & Fukuhara, 1989; Hishitani, 1990; Miller & Stigler, 1991). Taking one finding from this body of research to illustrate how the abacus mediates numerical thinking, it has been shown that the digit memory of expert abacus users is larger than it is for non-users. These skills arise because complex arithmetical problems performed with the abacus require users to hold intermediate arithmetical calculations in memory as they progress to a final solution. These intermediary steps are stored in working memory as visuospatial representations that may be analogical to the representation of numerals on the abacus. (Hatta, Hirose, Ikeda & Fukuhara, 1989; Stigler, 1984). The focus on the mediating role of artifacts is relevant to our understanding of numeric cognition because it reveals that the perceptual processes and the motor skills required for artifact use mediate and give structure to internal symbolic processes. These issues are beginning to be recognised in one model of number processing (Campbell, 1992). In the encoding complex model, Campbell explicitly states that number concepts may involve imagistic analogical representations (i.e. number line) and visuo-motor representations (i.e. counting on fingers or using the abacus). However, Campbell admits that neither a mechanistic nor a functional specification of these influences on number conceptualisation have been developed in his model, nor any other model of numeric cognition. Moreover, Campbell does not offer empirical evidence to support such views. Some empirical evidence for the mediating role of artifacts on number conceptualisation, is available in Dehaene's SNARC research which shows, as reviewed above, that the cultural artifact of writing affects the spatialisation of an internal number line. However, Dehaene's triple code model of numeric cognition does not explain why cultural artifacts affect numeric processing. Thus, it would appear that although the theoretical framework for these views has not been developed, there is some recognition that cultural artifacts might have some influence on number conceptualisation.

An Overview of the Two Current Studies of Numeric Cognition in Lebanese Seller Groups

Two closely linked studies will investigate how a cultural artifact, currency in the maths of selling practice, shapes number conceptualisation. The first study, herein termed the Bill and Numeral Recognition Study, investigated how sellers and non-sellers recognise numerals and currency bills. This study is an extension of Saxe's (1991) Bill and Numeral Identification study which examined how Brazilian child candy sellers and schooled non-sellers recognise numbers presented in isolation and numbers presented in the context of a bill. Saxe's main findings indicated that child street sellers, who practice orally based paperless numeracy skills, do not show skill at reading numerals outside the context of a currency bill. In comparison to sellers, schooled non-sellers have better orthographic numeral reading skills, as assessed in an off-line naming task. From these results, Saxe inferred, but did not provide direct evidence, that sellers have currency based representations of large numerals. The current investigation extends Saxe's research in two ways. First, the bill and numeral recognition skills which Saxe assessed in his off-line Bill and Numeral Identification task will be assessed in a speeded recognition task. The current task will be referred to herein as the Bill and Numeral Recognition task. A second way in which Saxe's study will be extended will be to examine the numeral recognition skills of two different seller groups. One seller group will be a traditional Lebanese group who practices orally based paperless selling practices. The other group will be a modernising Lebanese seller group who practices paper-based selling which involves reading monetary values outside the context of currency exchanges and transactions. The primary reason for examining the bill and numeral recognition skills in these two seller groups was to more directly investigate Saxe's hypothesis that orally based selling practices lead to the development of different bill and numeral recognition skills. The assignment of sellers to these two groups was based on ethnographic observations that identified socially embedded numeracy practices which Saxe (1991) argues give rise to the development of different numeric skills. A full ethnographic description of these numeracy practices will be reported in the introduction to the Bill and Numeral Recognition and Large Number Concept Priming Studies.

The second set of studies, herein termed the Large Number Concept Priming studies, involve a reanalysis of the recognition data to investigate whether the recognition skills observed in the first study were related to qualitative differences in number conceptualisation among the two seller groups. This was examined by studying whether a standard currency bill is primed by its own visuospatial properties or whether it can be primed by an orthographic numeral which represents the monetary value of a bill. In this priming study, I investigate for the first time whether the numeracy practices of Traditional and Modernising Sellers, compared to two non-seller groups, influence the way monetary values are conceptualised.

Saxe's Ethnographic and Descriptive Studies of Numeracy Skills in Brazilian Child Candy Sellers

The experimental study conducted by Saxe (1991) investigated the impact of schooling and selling experience on the way Brazilian child candy sellers and Brazilian school children recognised and represented large number concepts. It was based on ethnographic data and descriptive studies which revealed that these groups used numbers differently. The observational data that will be reviewed next is the basis for Saxe's main thesis that sellers have a currency-based representation of large numerals and not an orthographically-based representation. A currency-based numerical representation is one where the visuospatial properties of the currency bill are very salient. An orthographically-based representation of a number concepts is one where the orthographic features of the written numeral form are most salient. The evidence that the sellers have a currency-based representation is rather indirect, as will be shown.

Let's begin with some demographics of the groups involved in Saxe's study. The 23 sellers observed were all boys between the ages of 7 and 15 years (mean age, 12.6 years). They were not currently enrolled in school although they had been at one time. On average, they had three intermittent years of grade-school education, however there seemed to be considerable variability in their level of education. Saxe reports that some of the sellers received no formal education while others received up to 7 years of grade school. Based on these demographics one can see that school-based literacy skill varied considerably in these groups and was not controlled for in an exacting way. Nevertheless, Saxe did ensure that the all the sellers could read numerals. Furthermore, sellers' knowledge of standard numeral orthography was assessed in a task where they were required to read the value of 4 digit numerals which do not appear on Brazilian currency. Results showed that the seller and a schooled non-seller groups had at least the minimal levels of reading skill required to read numerals outside the context of a currency bill. The schooled non-seller group, which served as the main comparison groups, consisted of 20 children ranging in ages from 10-12 years (mean age 10.8 years). These children were from schools that the sellers had been enrolled in at one time.

In addition to collecting descriptive data from the seller groups, wholesale clerks, who worked where the child sellers bought their products, were also observed and interviewed. The wholesale clerks were recruited from 14 stores in downtown Recife, Brasil. They included females and males ranging in ages from 18-40. Nine out of 14 clerks kept written records over a period of 2-3 days detailing the type of assistance they offered the candy sellers during purchases.

A number of converging observations from ethnographic and survey methods lead Saxe to hypothesize that orally-based numeracy skills, which are emphasised in the selling practices of street sellers, affect number representation. Most of the evidence comes from observations of how sellers purchased candy from wholesalers. Children usually determined what kind of candy they wanted to buy, either based on past experience or from recent recommendations by other sellers, before entering a shop. Then they typically looked for the product and, if they didn't find it, they then went to another wholesaler. Sellers typically relied on oral communications for the wholesale price information either from the merchant in the store or from other sellers who had recently bought the product. Comparative shopping was circumvented because the sellers received price information from other sellers who had bought the product. This was a viable strategy for sellers to rely on the prices quoted by other sellers since the wholesale prices fluctuated frequently due to inflation and since listed prices do not reflect the value of a product but merely a base price from which to start bargaining. In further support of the view that orally-based, in comparison to literacy-based, numeracy practices were emphasised, Saxe reported that he did not observe the sellers reading numerals to determine and compare wholesale prices.

Based on these descriptive observations, Saxe conducted a study to gather frequency data about the numeral reading behaviours of sellers. For the first part of the study, an observational check list based on ethnographic observations described above was developed. Observers recorded a number of categories of behaviour. For the current investigation, I was interested in only the behaviour related to numeral reading during the purchase phase. In the Saxe (1991) study 45% of the sellers did not ask the clerk for prices, and from this group that did not ask for prices, 65% of them did not look for the price of the product on the shelf. As a follow-up to this observation, sellers were asked if they read the posted prices. None reported they read the prices. Moreover, of the 39 sellers who made a purchase, 41% said they already knew the price of the purchase from friends or from a previous purchase. Results also showed that 54% of the sellers asked the clerk for the price. Finally, the wholesale clerks were asked about the type of assistance they gave the child candy sellers during purchasing. They reported that they were asked about the wholesale prices in 55% of the purchases and in 45% of the purchases they were asked the number of units in the box.

Together these findings show, as the ethnographic observations suggest, that sellers can and most typically make purchases without numeral reading. Numeral reading is not obligatory in the purchasing practices of these candy sellers. In fact these findings and the ethnographic research suggest that oral communication rather than reading practices mediate purchasing. These findings show that numeral reading is not emphasised in the purchasing practices of Brazilian candy sellers and thus alternative forms of numerical representation that are supported by social practices may develop. Saxe posits that currency-based representations develop. These representations involve the encoding of all the visuospatial aspects of the bill pattern. In comparison to a currency-based representation, an orthographically based representation emphases the encoding of the written numeral form. The interpretation that sellers have a currency-based number concept fits with other findings in Saxe's research which show the minimal role that orthographically based maths literacy plays in selling practices, especially in arithmetical problem solving strategies of sellers which involve currency linked context-specific strategies that could not be used efficiently for other types of arithmetic problems. It is important to highlight that although the evidence reviewed here suggests that sellers have a currency-based representation, Saxe does not offer direct experimental evidence for a currency-based representation. But rather he shows that sellers have difficulty reading numerals that are not presented in the context of currency.

Views on the development of different numeric skills. Next, I will outline Saxe's account of why a currency-based, instead of an orthographically-based representation, develops in the seller groups. Adding to Saxe's account, I will review cross-cultural literacy research which offers another explanation of why a currency-based representation of numerals is an alternative to an orthographically-based representation. I will then discuss an experimental assessment of the numeral reading skills of sellers conducted by Saxe (1991).

First, according to Saxe (1991) sellers do not show an orthographically-based representation of large numerals because the skill of reading numerals in isolation, in comparison to the skill of reading numerals embedded in the rich visuospatial context of a currency bill, is not emphasised in street selling practices. Considering the numerical skills that sellers develop, Saxe does not offer a direct explanation of why a currency-based representation develops for numerals, except to broadly state that non-sellers engage in tasks that required them to have specialised knowledge of currency. It is not clear from Saxe's account what practices lead to the development of currency-based number representations. Saxe's ethnographic observations suggest that he holds that orally-based numeracy practices lead to strong linkages between number orthography and visuospatial context of the bill itself. However, it remains to be developed how orally-based numeracy practices lead to the development of stronger linkages between the numeral orthography and the visuospatial context of the bill. Various cross-cultural literacy studies, interpreted within the cognitive style framework, offer another explanation of why certain groups may de-emphasise highly contextualising literacy skills.

Heath (1983) studied Black American lower middle class preschoolers and observed pervasive differences in literacy practices. Highly contextualising Black children (as revealed in a number of cognitive domains such as discourse, scene perception, and reasoning) relied extensively on non-orthographic cues and spatial layout to make meaning out of printed numbers and words. She noted that although Black children readily recognised trademark names that appeared on cereal boxes or in advertisements, they had difficulty recognising printed numbers and words outside their familiar visuospatial context. A production task, where Heath asked children to draw things that had printed material on them such as newspapers or soup cans, further illustrated their highly contextualising literacy skills. Black children spontaneously reproduced the spatial layout of the printed material on these objects and various notational properties of the print such as the size of the words, in addition to reproducing the words.

A similar tendency to visualise how print looks in its surrounding context, and the added effort involved in making meaning out of words in isolation, have also been documented in Street's (1984) ethnographic study of the socio-cultural basis of literacy practices of Iranian merchants and farmers, and in Wagner's study of quaranic literacy practices in Morocco. Although, psychologically detailed observations of these practices are not available in either of these studies, the ethnographic data support both Saxe and Heath's observations of contextualising literacy practices in Non-Western European groups.

Review of Saxe's Experimental Bill Identification Study

The Bill Identification task was developed by Saxe (1991) to assess whether child sellers had developed highly specialised knowledge of the denominational structure and the visuospatial properties of currency, knowledge which exceeds that acquired through everyday buying practices. These sellers were compared to two different groups of non-sellers: schooled non-sellers with high levels of school-based numeracy skill, and rural non-sellers with low levels of both school-based and currency-based numeracy skill. The comparison of interest in the current investigation is between the seller group and the schooled non-seller group since seller and non-seller groups will be compared in the present investigation. Three bill types were used to assess how well children identified the value of bills and how well they recognised numerals. For the Standard Bill condition children were presented with twelve actual Brazilian bills. In the Numeral Occluded condition the children were presented with bills that had their numbers occluded. In the Numeral Only condition subjects were presented with cut-out black and white photocopies of numerals from the Standard Bill condition. The dependent variable was an off-line measure, namely the number of bills named. Results showed that schooled non-sellers performed significantly better than the sellers in the Numeral Only condition alone. The sellers typically made more decimal placement errors in naming Numeral Only bills compared to school non-sellers. The two other conditions, Standard Bills and Numeral Occluded Bills were named equally well by the sellers and the schooled non-sellers. Contrary to expectations, the sellers did not have better pattern recognition skills as measured by a number correct score. The final result to report is that all groups performed better on the Standard Bill and Numeral Occluded conditions compared to the Numeral Only condition, suggesting that all children had developed an ability to use the bills themselves to signify large values and did not necessarily need to read the values.

Saxe's results show a schooling practice effect. Numeracy skills, of the type learned in school, lead to better orthographic number recognition. However, the findings do not suggest a selling practice effect. Skilled sellers did not have better pattern recognition skills as assessed by an off-line measure, the number of correctly named Numeral Occluded Bills. The Numeral Occluded and not the Standard Bill condition is the critical condition to compare sellers and schooled non-sellers since it allows one to determine whether bill pattern recognition processes, separate from orthographic reading processes, are used to identify a bill. These findings which do not show a selling practice effect for Occluded Bill recognition but reveal a schooling effect for Numeral Only recognition are puzzling. Why does schooling experience affect orthographically-based number reading skill, and why is selling practice not related to bill identification?

A speed of processing interpretation of Saxe's (1993) findings. One explanation may be that the dependent variable employed by Saxe, number correct masks differences in the very fast visual recognition processes involved in recognising Numeral Occluded Bills, but does not mask differences in the slower reading processes involved in reading Numeral Only bills. It has been shown in the recognition literature that speed of pattern recognition is faster for chess experts than for novices for complex patterns that draw extensively upon background knowledge, (Charness, 1991). More recently, various studies have shown that experts recognise and categorise novel objects faster and in qualitatively different ways from novices (Gauthier, Tarr, Anderson, Skudlarski, & Gore, 1999; Gauthier, Williams, Tarr, Tanaka, 1998). Thus, it seems that pattern recognition speed is related to level of experience with such patterns. This relationship also holds for word recognition. That is, skilled readers who have high levels of exposure to print, name words faster than poor readers who experience less exposure to print (Chateau & Jared, 2000). Both the pattern recognition and the word recognition research demonstrate a relationship between level of expertise and recognition skill, suggesting that the same relationship may hold for bill and numeral recognition and selling experience. Of course there may be significant differences between the complex pattern recognition skills assessed by Charness and Gauthier et al., and the pattern recognition skills for familiar objects such as currency bills. Moreover, the relationship between numeral recognition speed and experience in reading numerals presented in isolation may or may not be the same as it is for word recognition. These are empirical issues, which will be taken up in the current Bill and Numeral Recognition study. The studies, to be presented here, investigate whether experience with currency and experience in reading numerals presented in isolation is related to speeded bill and numeral recognition. Measuring speed of processing will be especially important in the current investigation since automatic recognition processes will be assessed in adult populations who have extensive experience with currency.

Practice based interpretation of Saxe's findings. Based on Saxe's experimental results and ethnographic data which showed that unschooled sellers are not good at recognising numerals outside a bill context, I hypothesise that sellers with currency-based numeracy skills rely heavily on non-orthographic cues to support number recognition processes. In contrast to the sellers, I hypothesised that non-sellers with high levels of school-based literacy will be skilled at accessing number concepts solely through Arabic numeral orthography. These hypotheses are based on Saxe's observations of street seller reading practices which involve identifying numbers on bills and reading numbers on boxes and signs. These practices, in addition to involving the orthographic and phonological processes of reading, unavoidably involve other processes such as colour perception, and spatial and pattern recognition processes. These non-orthographic processes are an unavoidable feature of reading numbers in selling practice, and are more pervasive in the orally-based selling practices of street sellers than they are in school numeracy practices. It may be the case that they are optionally and habitually emphasised by skilled sellers, where Arabic numeral decoding skills are de-emphasized. This seems to be a viable cognitive strategy in selling practice, whereas it would not be viable in school maths, since in selling practice numbers are embedded in a rich context of non-orthographic information that is correlated with a particular monetary value. Taken together, Saxe's ethnographic observations and survey methods suggest that street sellers do not have orthographically-based numeral recognition skills but may have numerical skill which are strongly linked to properties of currency. However, Saxe does not offer experimental evidence to show whether sellers have currency based representations of numerals. Consequently, only indirect inferences about the skills of sellers can be drawn from Saxe's findings. The current Bill and Numeral Recognition study and the Large Number Priming study, which will be described shortly, were designed to more directly assess whether sellers have currency-based recognition and conceptualisation skills.

Models of the Relationship Between Numeral Reading Skill and Number Conceptualisation

At this point, it is necessary to step back and consider what is revealed by the observed differences in seller and non-seller numeral reading skills. Does this difference simply imply that the practice of reading numbers with minimal contextual cues ensures speeded notation-specific reading processes, or do these numeral recognition skills reflect deeper characteristics of number conceptualisation? Three models of numerical processing deal precisely with this question about the linkages between notational or decoding processes and number conceptualisation. The main issue in this body of work is the degree to which number conceptualisation is shaped by notation specific processes involved in decoding Arabic numerals (i.e., '6') or number word formats (i.e., the number word 'six') (McCloskey, 1992; Dehaene, 1992, Dehaene et al., 1993; Campbell & Clark, 1988; Campbell, 1994). Although, there are no studies in this literature that investigate how the "notational" features of artifacts, including both the perceptual and functional features, mediate number conceptualisation, the models and their implications for the current study will be outlined because they offer processing accounts of how surface notational processes affect number conceptualisation. A framework for thinking about how the notational features of number affect number conceptualisation is only available in the maths cognition literature and therefore the models that address this issue will be reviewed. The perspectives found in these models will then be applied to our particular question: can number recognition processes reflect qualitative differences in number conceptualisation?

The views offered in the models fall along a continuum from notation-specific hypotheses to notation-independent hypotheses, with the former positing stronger linkages between notation specific encoding and decoding processes and number conceptualisation, and the latter view positing complete independence between notation and conceptualisation processes. Models which posit stronger linkages between perceptually-based encoding processes and conceptual processes would predict that sellers' numeric recognition skills should be linked to aspects of their number concept.

The encoding-complex view. At the notation-specific end of the continuum, Clark and Campbell (1988; Campbell, 1994) offer the encoding-complex view. Here, I am concerned with the part of the model which proposes that numerical processes are grounded in modality-specific codes (visuospatial and verbal-auditory codes) that are interconnected in a complex and highly integrated associative structure (Campbell, 1994; however, see McCloskey, 1992 for an alternative interpretation). The most basic assumption of the model is that numbers are represented in terms of modality-specific mental codes and that these codes are posited to be central to numeric processes, not simply processes limited to encoding and decoding notation-specific input (i.e., the spoken word six). Linguistically-based numerical codes involve articulatory and phonological processes (in most people), and visual numeral and written number word codes in literate individuals. In addition to these codes, Campbell & Clark (1992, p. 459) posit that number codes may involve imagistic analogical representations (i.e., number line) and visuo-motor representations (i.e. counting on fingers or using the abacus). According to the encoding-complex view, these codes can activate one another and can be combined in various numerical tasks. The evidence used to support these claims is found in studies which show that the format of a stimulus presentation has an effect on semantically based numerical processes (Campbell & Clark, 1992; Campbell, Kanz, & Xue, in press). Taking one specific finding to illustrate the effects of format on number processing, Campbell and Clark (1992) found that when participants are given simple multiplication problems in Arabic numeral format (9 x 6) and number-word format (nine x six), their performance was faster and less errors were made in the Arabic format. For the word format, there was an increase in magnitude-based errors, i.e., the problem "9 x six" is incorrectly answered with the value 43. These results are taken as evidence that the numerical magnitude had a smaller influence on number-words compared to Arabic numerals. Results of this sort have been taken by Campbell and Clark as evidence that notational processes (decoding Arabic numerals and word formats) had an effect on central processes of magnitude information. Applying this model to bill and numeral recognition, it would hold that differences in numeral recognition reflect qualitative differences in number conceptualisation.

The abstract-amodal model. At the notation independent end of the continuum, McCloskey and colleagues' posit that all numerical inputs are obligatorily translated, via notation-specific comprehension modules, into an amodal abstract representation of numerosity (McCloskey & Caramazza, 1988; McCloskey, Sokol, & Goodman-Schulman, 1986; McCloskey, 1992; McCloskey, Aliminosa, & Sokol, 1991). Recall that a number concept is considered amodal if it does not include notation specific properties such as Arabic numeral features or number word features. According to McCloskey (1992), the number comprehension system converts the surface forms of numbers into a common abstract code, which then provides the basis for calculation or numeral production processes. According to McCloskey (1992), the notation-specific comprehension module passively passes information to the amodal representation but does not have access or involvement in the inner workings of it. Empirical findings for these claims are found in neuropsychological case studies of impaired patients (McCloskey, Caramazza, Basili, 1985; McCloskey, Sokol, & Goodman, 1986; McCloskey, 1992). Using this model to interpret the findings of Saxe's Bill Identification Task, the observed differences in numeral reading and pattern recognition among sellers and non-sellers would be attributed to notation specific processes and not number conceptualisation.

The triple code model. The triple code model (Dehaene, 1992, 1997; Dehaene, Bossini, & Griaux, 1993; Dehaene & Cohen, 1995), falls somewhere in between the encoding complex model and the amodal model in terms of how it views the linkages between notational processing and numeric conceptualisation. Unlike McCloskey's modular model, the triple code model claims that number processing operates interactively among three types of codes: the visual Arabic number code, the auditory verbal code, and an analogue magnitude code which has spatial properties (as revealed in SNARC studies). In agreement with McCloskey, Dehaene claims that the magnitude code is a bottleneck for all numerical processes as there is no direct route linking Arabic and verbal codes that does not have to pass through a magnitude representation. However, the triple code model differs from the amodal model, in that it posits that immediately after notation-specific processes, numbers are transcoded into whatever internal code is required for the task at hand. Consequently a number may be transcoded several times from one internal representation to another. The model remains modular in that each numerical procedure is supposed to be tied to a unique input-output code. This means that for some processes (the parity judgement task is an example) information is extracted in a similar way regardless of whether the input notation is a verbal numeral or an Arabic numeral because the input must be transcoded into a magnitude representation before parity information is available (Dehaene, Bossini, & Giraux, 1993, experiment 8 and 9; however, see Campbell & Clark, 1992, and Campbell et al., in press for an alternative explanation).

There are other studies, which show a stronger SNARC effect in tasks that involve Arabic numeral processing compared to written number word processing. These studies support the view that there is a modality-specific link between the Arabic numeral code and spatialised number conceptualisation. Dehaene argues that these findings do not support an extreme version of Campbell & Clark's (1988) encoding-complex model which holds that radically different mental representations are activated depending on the input notation of the target stimulus, since qualitative aspects of number processing do not always vary as a function of input notation. Dehaene et al.'s findings are also not in complete agreement with McCloskey's views, since there is evidence indicating that numeric and calculation processes can operate on notation specific codes. In sum, the triple code model proposes the following hypothesis: each type of numeric representation provides an in-road to specific output procedures. That is, past connections between input and output procedures will operate on specific number and knowledge retrieval processes. Depending on the strength of these connections, the input numeral notation will be strongly linked to its number concepts. In other tasks which demand the transcoding of one input code into another, notational processes have minimal or no impact on number conceptualisation procedures. Dehaene claims that these preferred pathways are dependent on processing procedures. That is, certain numerical tasks must be done on a particular representation. He does not offer an explanation of how these preferred pathways develop, but he curiously rejects statements by Campbell and Clark (1988) which claim that the link between numeric operations and specific notation processes is dependent on an individual's idiosyncratic learning history, culture-specific strategies, and other skill related factors (Dehaene, 1992, p. 33). According to the triple code model, the linkages between notation specific processes and number conceptualisation are not shaped by artifact use, and thus differences in naming speed only reflect decoding or transcoding processes and not qualitative differences in number conceptualisation. This statement by Dehaene (1992) seems to contradict later SNARC effect research which showed that writing practices affect number conceptualisation. Based on this contradiction, it would be reasonable to conclude that Dehaene has not developed frameworks for thinking about how culturally specific practices and artifacts affect numerical processing. Nevertheless, the model does suggest that input-output procedures may affect number conceptualisation. If this is the case then, one' s level of decoding experience with a particular notation should affect how numbers are conceptualised.

The models outlined here disagree in their views concerning the extent to which notation-decoding processes affect number conceptualisation. Since there are no known direct empirical findings which would lead us to predict the effect that currency-based numeracy practices compared to school-based numeracy practices have on number conceptualisation, a task was devised to study bill and numeral recognition processes in Traditional and Modernising sellers and non-seller groups. These issues will be taken up presently in the Bill and Numeral Recognition Study. Moreover a second study, here labelled the Large Number Concept Priming study, was designed to examine whether speed of bill and numeral recognition is motivated by underlying conceptual processes. The priming study was not designed to discriminate between the models described above. Nonetheless, the study takes up the issue of how recognition processes involved in bill identification and numeral reading are related to how sellers and non-sellers conceptualise numbers. Next, we turn to an overview of the Bill and Numeral Recognition study.

Chapter 5: Introduction to the Bill and Numeral Recognition and Large Number Concept Priming Study

Ethnographic Observations of Traditional and Modernising Lebanese Selling Practices

Saxe's research has provided a starting point for investigations of the differing maths cognition of schooled and unschooled people, and of sellers and non-sellers. Recall Saxe's claim that numeric skills arise out of pervasive aspects of socially embedded math numeracy practices. Continuing and extending Saxe's line of inquiry, the first phase of the current study investigated the everyday numeracy practices of two Lebanese seller groups, a traditional and a modernising Lebanese seller group. In the ethnographic phase of the current investigation, I observed the selling practices of a wide range of store owners and store clerks in Lebanon. I observed a number of correlated practices that I have summarised with the term "paperless" selling practice, which contrasts with "paper-based" practices. Paperless numeracy practices were most common in traditional Lebanese business practices, and "paper-based" practices were observed and emphasised to a greater extent in modernising Lebanese business practice. The two groups investigated will herein be referred to as Traditional Sellers and Modernising Sellers. Observations of these groups were, in turn, used to generate falsifiable predictions about how Traditional and Modernising Seller groups recognised bills and numerals. It was predicted that paperless numeracy practices which were observed in Traditional selling practice would lead to contextualising currency-based bill and numeral recognition skills. A highly contextual representation of a currency bill would involve strong linkages between the monetary value of the bill and its visuospatial properties. Traditional Sellers may show highly contextualised representations because traditional business practices do not emphasise nor require high levels of skill with monetary values not linked to currency, as will be described shortly. For Modernising selling practices which involved higher levels of skill in paper-based transactions where monetary values are not directly linked to currency, it was predicted that Modernising Sellers will show decontextualising bill and numeral recognition skills. The observations that lead to these hypotheses will be reviewed next. For both the Traditional and Modernising sellers, I will describe the settings of the stores where they worked before I describe their numeracy practices.

Traditional Selling Practices

The ten Traditional Sellers were either owner/operators or family members working as full time clerks of five small businesses in the Bekka region in Lebanon. Five of the participants worked in "dukanas" (similar to Canadian convenience stores) in the small villages of Medouka and Ata El-Foukar (population under 300). The other five Traditional Sellers worked as clerks in a family-run clothing store in the near-by city of El-Masna, which is the last commercial centre on the highway out of the Bekka to Syria.

Printed material does not play a central role in the numeracy practices of Traditional Sellers. Instead orally-based numeracy practices are emphasised in many aspects of business practice. Beginning with observations of the sales transactions, none of the businesses had cash registers and clerks did not give out sales receipts which itemised purchases. Cash registers and sales receipts are not a legal requirement in Lebanese businesses due to longstanding political instability that make it impossible to collect retail taxes. During a sale, clerks typically summed the value of the products out loud as they pointed to each item and stated its price. Calculators were rarely used since the value of the products purchased was not high and the number of products rarely exceeded five items. Moreover, calculators were not needed since items could be added easily because prices in small village stores were rounded-off to whole bill currency units, and there was no need for complicated tax calculations. At the end of a sales transaction, clerks were never observed, in a 4 month time span, giving out hand written receipts. Receipts were not even used when customers bought on credit, which they did frequently. For these transactions, the clerk added up the purchases out loud for the customer to hear and agree upon. Once the customer left the shop, the clerk entered the amount owed in a log book that listed how much each customer owed. It was considered impolite to do this in front of the customer. Most clerks did not enter the date of the transaction, but simply the amount owed for each transaction and the balance. These details were not necessary since the store clerk personally knew each customer, usually through kinship. The logs served only as a personal reminder to the store-owner to request payment or limit purchases. They could not, in and of themselves, be used to prove how much the customer owed if a dispute arose independent of social considerations such as the customer's status in the community, and the kin relation.

Paperless numeracy practices were also observed in the way Traditional store-owners and clerks purchased merchandise for their store. The amount of the purchased products was summed orally and no receipts were issued or requested. Part of the reason for this is that most distributors work for themselves and were not accountable to their employer for cash flow balances. It is almost certainly the case that some of the truck drivers who worked for distributors, issued receipts to keep a record of the products sold. However, since I did not observe these kind of distributors working in small villages I cannot comment on how invoices and other printed material were used. It is clear, however, that among Traditional Sellers it was not typical for receipts to be issued. Further evidence that numeral reading was de-emphasised is as follows;

the price of items was not marked on the products nor were they printed on a price list. Shopkeepers memorised the prices of their merchandise. These Traditional work practices emphasise the development of oral numeracy practices. This conclusion is further supported by the observation that many clerks and storeowners in small Lebanese villages are functionally illiterate but still manage to run their businesses quite successfully in a kinship based market.

Comparing the Lebanese Traditional Sellers to Saxe's street sellers. The Traditional sellers of the current investigation are different in a number of ways from Saxe's candy sellers, even though both sellers groups emphasise orally-based paperless numeracy practices. The Traditional Lebanese sellers, unlike Saxe's sellers, were all literate and had completed at least grade-school levels of education. Moreover, the Traditional Lebanese sellers worked in shops where the requirement to make speeded currency-based calculations is not as strong as it is for street sellers who have only a limited amount of time to make change for customers on the go. The requirement to make speeded calculations results in a strong currency-based representation of number structure, as shown in Saxe's experimental studies of seller and non-seller mental arithmetic. It may well be that the requirement to make speed calculations with currency is a central cognitive skill which differentiates the numerical skills of sellers and non-sellers. A group of Lebanese street or push-cart sellers would have been more comparable to Saxe's street sellers and would have provided a maximal contrast to the Modernising Seller group which will be described next. However, push cart sellers were not assessed in the current investigation, since I had no place to administer the experiments in the busy open markets and along the highways where the push cart sellers worked.

Modernising Selling Practices

The Modernising Sellers were owners or clerks of medium-sized shops that were either located in larger commercial city centres or on main road-ways outside small villages in the Bekka region of Lebanon. Six of the nine Modernising participants owned and operated their businesses, and were involved in all aspects of business practice from sales to purchasing to bookkeeping. However, they were observed to spend a higher percentage of their time doing administrative and managerial duties such as banking and bookkeeping and keeping employees on task. This is a marked difference from Traditional store owners who were observed spending most of their time socialising with their customers. The customer base of these medium-sized stores was much larger than the familial customer base of the small village shops where Traditional Sellers worked. Another main difference is that four out of the eight modernising businesses from which I recruited participants, had small distribution outfits in addition to retail sales. These modernising business practices resulted in more employees, many of whom were not kin related, contrasting with family operated traditional businesses.

Observations of the daily business practices of Modernising Sellers showed a stronger emphasis on paper-based numeracy practices. Five out of the eight Modernising businesses made use of cash registers or receipt books to record retail transactions. Sales receipts were used for accounting purposes; they were not given out to customers. Receipts, used as a means to monitor daily income, may serve a more central role in Modern business practices where the work activities of many employees must be coordinated and monitored. In addition to these written records, Modernising sellers kept logs of their customers' credits. It was necessary for these logs to be very precise and accurate since Modernising sellers had a larger customer base. I observed sellers record customer purchases and collect money from customers. Modernising store owners and sellers complained bitterly about managing customer credit; however, it is largely unavoidable in Lebanon since credit cards and cheques are not widely accepted. Based on these observations of numeracy practice in Modernising businesses, it was hypothesised that the requirement to read and write numerals and monetary values not directly linked to currency emphasises the development of decontextualising bill and numeral recognition skills in Modernising Sellers.

In addition to the Traditional and Modernising Seller groups, two comparable Traditional and Modernising Non-seller groups were administered the Bill and Numeral Task. A description of these control groups can be found in the Methods section.

Overview of Bill and Numeral Recognition Study

The Bill and Numeral Recognition task was designed to study the first empirical question that arose in the review of Saxe's findings; that is, do skilled sellers with currency-based numeracy skills emphasize visual information and de-emphasize orthographic information in bill identification, in comparison to non-sellers? Naming time will be the dependent measure employed here. It is a more sensitive measure than that employed by Saxe. I will assess the length of time it takes Traditional and Modernising Lebanese Sellers and two comparable

Non-Seller groups to name four types of bills: Standard, Numeral Occluded, Currency Numeral Only, and Non-Currency Numeral Only Bills. This last bill type, Non-Currency Numeral Only, was a new bill stimulus used only in the current investigation. Non-Currency Numeral Only Bills displayed numerals that do not appear on standard Lebanese bills in a bill like frame (i.e., 2,000, 6,000, 11,000, 21,000, 51,000; see Appendix I for a pictorial representation). The rationale for the use of Non-Currency Numeral Only bills will be described presently as each prediction is outlined.

Four comparisons in these bill naming times will be made to assess bill and numeral recognition processes in the Traditional and Modernising Seller and Non-Sellers groups. First, I looked at naming times for Numeral Occluded and Currency Numeral Only Bills. Based on my ethnographic observations and Saxe's Bill and Numeral Identification findings, it is predicted that Modernising Sellers who use paper invoices and receipts in daily business practice, which requires them to recognise and think about numerals outside a bill context, will show faster Currency Numeral Only naming. Second, the Standard bill naming times for the four groups will be compared. The Traditional and Modernising Seller groups, each compared to their respective Non-Seller groups, are predicted to show faster Standard Bill naming times because they have more experience with currency. This prediction is based on the expertise literature reviewed above. A third way of assessing bill recognition processes will be to compare naming times for Standard Bills and Numeral Occluded Bills. If the visuospatial processes involved in bill recognition are greatly emphasised while orthographically based processes are de-emphasized in a particular group, than that group should show little difference in the time it takes to name Standard Bills and Numeral Occluded Bills since the absence of numeral orthography should not greatly slow down recognition. It is predicted that the difference in these naming times will be smaller for Traditional Seller groups compared to Modernising Seller groups. This prediction is based on Saxe's research which suggests that bill recognition in seller groups who emphasise oral numeracy practices is driven by visuospatial processes instead of orthographic processes. Within the Traditional group, Traditional Sellers compared to Traditional Non-Sellers are predicted to show the least difference between Standard Bill and Numeral Occluded Bill naming because they have more experience with currency. A final way in which the numeral recognition skills of the groups will be assessed will be to compare naming times for Currency Numeral Only bills to naming times for Non-Currency Numeral Only bills. Recall that Non-Currency Numeral Only bills have values that do not appear on standard Lebanese bills. For this comparison, it was reasoned that if sellers' number concepts are grounded in the currency system, compared to a written symbol system, than the identification of non-currency-based numbers that do not appear on bills, should be slower than the naming of currency-based numbers that appear on a bills. Consequently, it is predicted that performance in these conditions will vary with selling experience such that the sellers, compared to non-sellers, will name Currency Numeral Only Bills faster than Non-Currency Numeral Only Bills. Moreover, since Modernising Sellers have more skills with orthographically based representations that are not directly linked to currency, it is predicted that the difference in the naming time will be greater for Traditional

Sellers compared to Modernising Sellers.

Overview of Large Number Concept Priming Studies

The Large Number Concept Priming study investigated whether there are qualitative differences in the way the Traditional and Modernising Sellers and their respective control groups conceptualise large numbers. The data gathered for the Bill and Numeral Recognition Study were reanalysed in the Large Number Concept Priming study to assess how the four groups conceptualised monetary values and whether these conceptualisations showed strong linkages between a monetary value and the visuospatial context of a bill. These processes were assessed in a continuous priming situation where participants were presented with two kinds of prime-target pairs. In the Currency Numeral Only-Standard Bill prime-target pairs participants named Numeral Only bill which was either related or unrelated to a Standard Bill which they also named. A related bill was one that had the identical monetary value of the Standard Bill, and an unrelated bill had a different value. In the Numeral Occluded-Standard Bill prime target pairs, participants named a Numeral Occluded Bill followed by a related or unrelated Standard Bill.

A priming effect arises when there is an improvement in processing created by an earlier experience. In this study priming would be indexed by faster naming times for related compared to unrelated trials. In line with the standard priming study rationale, if a number concept's pattern of activation is related to, or overlaps, with the pattern of activation for a concept activated after the first concept, then higher levels of priming will result. Based on the ethnographic observations of Traditional and Modernising Sellers' numeracy practices, it is hypothesised that the strength of the linkage between the body of the bill and its numeric value would be greatest for Traditional Sellers, compared to Modernising Sellers and both Non-seller groups. If this is the case, then significantly different levels of priming would be observed for the Numeral Occluded-Standard prime-target pairs compared to the Currency Numeral Only-Standard pairs. It is predicted that Traditional Sellers compared to Modernising Sellers and both Non-Seller groups would show the highest levels of priming for the related Numeral Occluded-Standard Bill prime-target pairs. For the Currency Numeral Only-Standard Bill prime-target pairs, the Modernising Seller groups are predicted to show higher levels of priming compared to the Traditional Seller group and the Non-Seller groups.

Method

Bill and Numeral Recognition and Large Number Concept Priming Studies

Participants

Four groups of literate Lebanese participants residing in Lebanon were administered the Bill and Numeral task. There were 10 Traditional Sellers, 9 men and 1 women ranging in ages from 19-39. In the Modernising Sellers group there were 10 men ranging in age from 22-39. There were 7 female and 3 male Traditional Non-Sellers ranging in age from 17-45. In the Modernising Non-Seller group, there were 5 females and 5 males, ranging in age from 19-44.

A number of criteria, together with ethnographic observations, were used to assign participants to one of the four groups. A participant was considered a seller if they were employed, on full time basis for a period not less than two years, as a clerk in a retail business that required frequent and rapid exchanges of money for goods. Occasional or part-time clerks who were less skilled with rapid economic transactions were not included in the current sample. Non-sellers were individuals who were either not employed or employed in a non-retail job such as construction.

The ten Traditional Sellers participated in traditional selling practices, as described in detail above. Traditional Sellers had up to but not beyond a high-school level education in state-run Lebanese or Syrian schools. Five of the Traditional Sellers were Lebanese working in small food shops, and five were Syrians working as paid apprentices in clothing shops. The Traditional Non-Seller control group had up to but not beyond a grade-school level of education and did not work as sellers. Eight of the ten Traditional Non-Sellers were homemakers, and the other two participants worked in construction.

A Modernising Seller participated in Modernising Selling practices, as described above. All the Modernising Sellers had at least high-school levels of Western education. Four of the nine sellers had finished a bachelors degree in Lebanese state-run universities. It is important to note that beyond differences in selling practices, Modernising sellers compared to Traditional Sellers have higher levels of education. Consequently, there is an unavoidable correlation between level of modernisation (as it is revealed in selling practice) and level of education. This correlation is observed in many cross-cultural psychological studies (Berry, Van de Koppel, Annis, Bahuchet, S., Cavalli-Sforza, & Witkin, 1986; Cole, 1996, for a review; Cole, Gay, Glick, & Sharp, 1971; Heath, 1983).

There were ten Modernising Non-Sellers. All had completed at least high-school level schooling. Four Modernising Non-Sellers had completed an undergraduate university degree, and three completed teacher college training. The Modernising Non-Sellers worked as teachers or telephone operators, and three of them were university students.

Apparatus

A MacIntosh Powerbook G3 laptop with a 14" Colour Liquid Crystal Display Monitor was used to present the stimuli. A MacIntosh Simple Talk external microphone connected directly into the computer was mounted on the right side of the screen. The application program Superlab (version 1.74; Cedrus Corporation) was used to display stimuli, and to record and time participants' responses to the nearest millisecond.

Materials and Scoring

In the Bill and Numeral task participants were presented with four types of visual stimuli. The Standard Bill stimulus type was the front face of each of the most widely exchanged Lebanese paper bills: 1,000 lira, 5,000 lira, 10,000 lira, 20,000 lira, and 50,000 lira (see Appendix F). There were five Numeral Occluded Bill types, one for each Standard Bill (see Appendix G). The Numeral Occluded Bills were identical to the Standard Bills except that all writing and numerals were occluded so that the identity of the bills could not be apprehended by reading the value of the bill. There were 5 Numeral Occluded Bills with the same values as the five Standard Bills. For both the Standard Bill and the Numeral Occluded Bill stimulus, the bills were the actual size of the real bill and they were scanned into the computer in a way which preserved subtle visual properties, such as the watermarks and colour tints. The Currency Numeral Only type were stimuli on which the numerals appeared in the positions used on a standard bill. The numerals appeared in the top right corner and the bottom left corner in a solid white rectangle with a thin black frame (see Appendix H). There were five Currency Numeral Only stimuli, with the same values as each of the Standard Bills. The Non-Currency Numeral Only stimuli were identical in appearance to the Currency Numeral Only stimuli except the numeral which appeared in the corners of the bill frame were numerals which differed from each of the currency numerals by a value of 1,000 . There were five Non-Currency Numeral Only stimuli: 2,000, 6,000, 11,000, 21,000, and 51,000 (see Appendix I).

The second purpose of the Bill and Numeral task was to assess whether number concepts are primed by one of two bills : the Currency Numeral Only Bills (Numeral Only priming) and the Numeral Occluded Bills (Numeral Occluded priming). In this continuous priming task where participants named every bill presented on the screen, the length of time it took to name related and unrelated target Standard Bills was compared for each priming type. For the related trials the prime was either a Numeral Occluded or a Currency Numeral Only Bill and the target was a Standard Bill of the same value. In the unrelated trials the Standard Bill did not have the same value as the two types of primes. The dependent variable was the length of time it took to name a related compared to an unrelated Standard Bill that was primed by a Numeral Only or a Numeral Occluded Bill.

Stimuli. The target bills had one of four possible values 1,000, 5,000, 10,000, 50,000. The value of the prime-target pairs depended on whether they were related or unrelated. Taking Numeral Occluded priming as an example first, related primes for each of the four target values were presented four times such that there were 16 related prime-target pairs for Numeral Occluded priming. For example in the related pair trials, a target Standard Bill with a value of 1,000 was paired with four Numeral Occluded Bills with a value of 1,000. The second set of 4 related prime-target pairs was for the value of 5,000. The third set of 4 related prime-target pairs was for the value of 10,000 and the same was done for the value of 50,000. For the 16 unrelated prime-target pairs, each of the four Standard Bills was paired with four Numeral Occluded Bill primes that did not have the same numerical value. For example, a target Standard Bill with a value of 1,000 was paired with four unrelated Numeral Occluded Bills with a values of 5,000, 10,000, 20,000, and 50,000. For the second set of unrelated prime-target pairs, the value of the target Standard Bills was 5,000 and the unrelated bills had a value of 1,000, 10,000, 20,000, and 50,000. The third and fourth sets of unrelated prime-target pairs that were for the values of 10,000 and 50,000 had an identical structure. Looking at the number of targets that were named and considering both types of priming, Numeral Occluded and Currency Numeral Only, participants named: 16 Standard Bills primed by an related Numeral Occluded Bill, 16 Standard Bills primed by an unrelated Numeral Occluded Bill, 16 Standard Bills primed by a related Numeral Only bill, and finally 16 Standard Bills primed by an unrelated Numeral Only bill. In total 64 Standard Bills were named, 32 Numeral Occluded prime types were named and 32 Numeral Only prime types.

In addition to the paired trials for the priming portion of the study, additional single trials, which were not paired with any other trials but appeared in random order, were included to assess naming times for the Non-Currency Numeral Only stimuli. Sixty-four Non-Currency Numeral Only stimuli were included in the Bill and Numeral task. Moreover, an additional 32 Currency Numeral Only Bills were added as single trials to enable a comparison between Currency Numeral Only and Non-Currency Numeral Only naming times. Finally, an additional 32 Numeral Occluded Bill were added as single trials since there were only 32 Numeral Occluded Bills from the paired trials. It was necessary to include each of the additional single trials so that we could compare the naming times for all four bills. In total, 64 bills from each of the four bill types were named for a total of 256 bill presentations. Participants received 128 randomly presented single and paired trials in the first block and the remaining 128 single and paired trials in the second block.

Procedure

All the participants in this task were given the following instructions in Arabic in the training-practice phase of the task:

> "You will see pictures of Lebanese bills on the screen. You will see 1,000 lira, 5,000, 10,000, 20,000, and 50,000 lira. Some of the pictures will be exactly like real bills, and others will be bills that have their writing and numerals occluded. You will also see bills that only have numerals on them, and you will also see bills which I made up that have numbers on them that you would not see on a real bill. For example you will see bills with these numerals on them.

Participants were then shown the following numbers and asked to name them: 2,000, 6,000, 11,000, 21,000, and 51,000. Participants who could not reliably name, or took a long time to name the stimuli were not included in the current sample of participants. Four traditional sellers with minimal levels of literacy were given the Bill and Numeral task but their scores were not included in the results because they made too many mistakes naming the Currency and Non-Currency Numeral Only Bills, and because they were visibly tired and inattentive before the end of the experiment. One other participant from the Modernising Seller group was not included because the testing session was interrupted several times and I was unable to readminister the task at a later time.

After these instructions, participants were given practice trials until they received all the stimuli at least once, or until they made no naming errors and I felt they were attempting to respond as quickly as they could. The participants were given only enough practice trials to meet these basic criteria since it is was also important that they were not over-taxed for the test trials.

For the test phase of the study, participants were instructed to name the stimuli presented on the screen. The stimulus was displayed on the screen until there was a verbal response. It was followed by an interstimulus interval of 600 msec. Participants named 128 trials in the first block and 128 trials in the second block. In between blocks they received a break until I felt they were rested and could offer their full attention for the remaining trials. During the break, participants and I usually chatted about politics, the West, how a woman travelling without a husband or father should behave, and with some participants about research. Generally, I found participants attentive and willing to respond to each trial as quickly as they could since they assumed that I was testing their speed of wit or intelligence. They were very embarrassed when they made errors. Some stopped and allowed several trials to pass as they apologised or made excuses for themselves. In such cases I started the testing session again, or if the disruption was not too long, I noted which trials were not named and did not include them in the statistical analysis. Due to interruptions such as this and other general interruptions such as those described in detail for the SNARC studies, reaction time data for some trials had to be taken out of the analysis since they could not be used to accurately assess the automatic processes of bill and numeral recognition. Appendix J provides a breakdown of the number of non-trials for each type of stimulus for each group, as well as outlier trials and errors. A trial was considered an outlier, if it varied three or more standard deviations from the mean for all bill and numeral naming times. A trial was considered an error when the value of the stimulus was named incorrectly. Inspecting Appendix J, no visible patterns in the distribution of non-trials and outliers were observed. The high rate of non-trials is attributable to the less-than-ideal settings in which the experiments were conducted. These testing conditions were described in detail in the SNARC procedure section. Inspecting the error rates broken down by bill type in Appendix J, the Traditional groups of Sellers and Non-Sellers seemed to make more errors for the two Numeral Only bills. This trend in the error data parallels their difficulty with naming these bills, as we will see shortly.

Upon completion of the task, many complained that it was tiring on the eyes. Also many participants attempted to identify, to no avail, patterns in the randomised presentation of trials, as they were looking for a rationale for the large number of repetitive trials. The majority of the participants, however accepted the novelty of the task without comment and participated because they felt socially obligated.

Results and Discussion

Study 2a: Bill and Numeral Recognition Study

The results from the Bill and Numeral task were analyzed as two separate studies. In the first one, herein called the Bill and Numeral Recognition Study (Study 2a), an analysis of variance assessed how Sellers and Non-Sellers and Traditional and Modernising groups recognised Standard, Numeral Occluded, Currency Numeral Only, and Non-Currency Numeral Only Bills. In the second study, the Large Number Concept Priming Study (Study 2b), a separate analysis of variance was conducted to assess two types of priming: Currency Numeral Only priming and Numeral Occluded priming in the Seller and Non-Seller groups and in the Traditional and Modernising group. Tables which summarize the complete analyses of variance for each study are shown in Appendices K and L respectively.

A 2x2x4 analysis of variance was conducted to assess whether the two between-subjects factors (selling practice and level of modernisation) affected naming speed at the four levels of the within-subjects factor (Standard, Numeral Occluded, Currency Numeral Only, and Non-Currency Numeral Only Bill naming). A summary of the full analysis of variance results for this study appears in Appendix K.

Within-subjects Main effects

There was a significant difference in the length of time it took to name each of the four bills, $F\ (3,105) = 99.01$, $p < .001$. As can be seen in Table 4, the Standard Bills were named faster by all groups followed by the Numeral Occluded Bills, followed by the two Numeral Only Bills.

Table 4

Bill and Numeral Recognition Study: Naming times in milliseconds for the Standard, Numeral Occluded, Currency Numeral Only Bills, and Non-Currency Numeral Only Bills

Groups	Standard Bills	Occluded Bills	Currency Numeral Only Bills	Non-Currency Only Bills
Traditional Non-Sellers (n=10)	825 (54)	896 (63)	1033 (106)	1133 (111)
Traditional Sellers (n=10)	724 (46)	797 (72)	871 (94)	865 (54)
Mean	774 (71.7)	846 (83)	952 (128)	999 (162)
Modernising Non-sellers (n=10)	774 (74)	849 (87)	908 (108)	916 (122)
Modernising Sellers (n=9)	670 (67)	739 (77)	803 (79)	807 (91)
Mean	722 (87)	794 (98)	856 (107)	862 (120)

Tukey HSD post hoc tests compared the naming times for each of the four bills, collapsing across level of modernisation and selling practice. The alpha level was set conservatively at $p < .01$. Results revealed that the Standard Bills ($M = 748$, $SD = 83$) were named faster than the Numeral Occluded Bills ($M = 820$, $SD = 93$), $Q(3,105) = 8.65$, $p < .001$. The Numeral Occluded Bills were in turn named faster than both the Currency Numeral Only Bills, ($M = 904$, $SD = 126$), $Q(3,105) = 10.04$, $p < .001$, and the Non-Currency Numeral Only Bills, ($M = 931$, $SD = 157$), $Q(3,105) = 13.24$, $p < .001$.The naming times for the Currency and Non-Currency Numeral Only Bills were not significantly different, $Q(3,105) = 3.19$, n.s.

These findings show that all groups named the real-world bill, the Standard Bill, faster than the novel Numeral Occluded Bill. Thus the absence of the numeral significantly slowed down bill recognition. Moreover, the Numeral Only Bills which consisted of numerals presented without most of the bill context were named the slowest. Currency Numeral Only Bills were named 156 milliseconds slower than Standard Bills, and the Non-Currency Numeral Only Bills were named 183 milliseconds slower than Standard Bills. Thus it seems that the absence of visuospatial bill context even more dramatically slows down recognition. The evidence which shows that the absence of the visuospatial context slows down recognition more than the absence of orthography suggests that the visuospatial properties of the bill provide a psychologically real context for orthographic recognition. This emphasis on context in numeral recognition is taken as evidence for a contextualising style of thought in these Lebanese groups. This contextualising style has been revealed in one other study which experimentally investigated the cognitive styles of Middle-Easterners in the domain of deductive reasoning (Zebian & Denny, 1996). Past cross-cultural and anthropological research has shown that this level of contextualisation is not observed in Western groups who show high levels of decontextualised thinking (Berry, 1976; Berry, van de Koppel, Senechal, Annis, Bahuchet, Cavalli-Sforza, & Witkin, 1986; Cole, Gay, Glick, Sharp, 1971; Chafe & Danielewicz, 1987; Davis & Denny, 1989; Denny, 1986, 1991; Heath, 1983; Hutchins, 1980; Lave, 1996; Scribner, 1977).

The bill and numeral naming times for the Lebanese groups, together with the wealth of research on cross-cultural variability in contextual and decontexual thinking gave rise to a study that was run only after the results from the Bill and Numeral Recognition study were analyzed. To assess the cross-cultural generalisability of the findings from the Lebanese groups, the Bill and Numeral Recognition task was administered to a group of university-educated Euro-Canadian Non-Sellers, known to be skilled at decontextualised school-based numeracy practices which involve thinking about and reading numerals when they are not connected to specific visuospatial contexts. A Euro-Canadian Seller group was not assessed in the current study since it was not possible to find a group of Euro-Canadian sellers comparable to either of the Traditional or Modernising Lebanese Seller groups. The task administered to the Euro-Canadian Non-Seller group was identical to the one the Lebanese participants received except that the bills were Canadian currency and the numerals for the Numeral Only bills were International Arabic numerals. It was reasoned that, if the Euro-Canadian group is highly decontextualising they should show a different pattern of results from those observed in the Lebanese groups, namely, Numeral Only bills should not take longer to name than the Standard Bills since reading the numeral on the bills should not be more difficult than reading a numeral presented in isolation. Moreover, it is predicted that Numeral Occluded Bills will be named significantly slower than Standard Bills and Numeral Only Bills because numeral orthography cannot be used to identify the value of a Numeral Occluded Bill; instead the visio-spatial properties of the bill must be processed before it can be identified.

Results of a completely within-subjects analysis of variance with ten university students of Euro-Canadian descent revealed an overall significant difference in the time it took to name each of the four types of stimuli, F (3,27) = 30.208. $p < .001$. Tukey HSD post hoc tests were conducted to assess which bills were named faster. Results showed that Standard Bills (M = 628, SD = 104), were named faster than Numeral Occluded Bills (M = 783, SD = 133), Q (3,27) = 12.88, $p < .05$. These results parallel those observed in the Lebanese groups. Thus it seems that for both the Lebanese and Euro-Canadian groups, the absence of numeral orthography significantly slows down bill identification. The other findings from these post hoc tests revealed interesting differences in numeral recognition. There were two novel findings observed in the Euro-Canadian group. First, Standard Bills (M = 628, SD = 104) were not named significantly faster than Currency Numeral Only Bills (M = 665, SD = 86), Q (3,27)= 3.08, n.s. This finding contrasts with the significantly faster Standard Bill compared to the Numeral Only Bill in the Lebanese groups. This finding confirms the expectation that Euro-Canadian groups are decontextualising in their numeral reading skills. A second and quite notable finding was that the Euro-Canadians named Numeral

Occluded Bills slower than Currency Numeral Only Bills, (M = 665, SD = 86), Q (3,27) = 9.80, $p < .01$, and Non-Currency Numeral Only Bills, (M = 669, SD = 101), Q (3,27) = 7.20, $p < .01$. Again this finding contrasts with the naming times in the Lebanese group which showed significantly faster Numeral Occluded compared to Numeral Only naming. Looking at the final comparison between the Standard Bill and the Non-Currency Numeral Only Bills, the university Euro-Canadian group showed faster Standard Bill naming times, Q (3,27) = 5.66, $p < .05$, a finding similar to that described earlier for the Lebanese groups.

Together the results from the Lebanese and University Euro-Canadian groups suggest that the absence of a numeral in the Numeral Occluded Bill greatly slows down bill recognition in both groups, but especially in the Euro-Canadian group. Euro-Canadians Numeral Occluded naming times are not only slower than Standard Bill naming but also slower than both Currency and Non-Currency Numeral Only naming. Moreover, the finding that Euro-Canadians, but not Lebanese, do not name Standard Bills significantly faster than Currency Numeral Only Bills shows that the Euro-Canadian control group is skilled at recognising numerals outside a visuospatial context, presumably because they are skilled at decontextualised numeracy practices. This finding is taken as evidence that the linkage between the visuospatial properties of a bill and the numeral orthography is not as tight for the Euro-Canadians as it is in the highly contextualising Lebanese groups. This emphasis on contextualisation in the Lebanese groups, taken as a whole, will be looked at more carefully in the following results which assess whether each of the four groups taken separately show more or less emphasis on contextualised bill and numeral recognition processes.

Between-subjects Main Effects

Returning to the main study, the two other main effects were the between-subjects effects for selling practice and level of modernisation. Collapsing across the naming times for the different bills, results showed that Traditional and Modernising Sellers (M = 784, SD= 72) named the stimuli faster than Traditional and Modernising Non-Sellers (M = 919, SD= 70), F (1,35) = 33.18, p < .001. Moreover, the between-subjects effects for level of modernisation, revealed that the Modernising groups (Sellers and Non-Sellers combined), (M = 808, SD= 72) responded faster to all the stimuli, compared to the Traditional groups, (M = 893, SD=70), F (1,35) = 13.51, p = .001. These between-subjects effects suggest that Sellers and Modernising participants, who have more experience with currency, respond more quickly to all bills. The interaction for the two between-subjects effects of selling practice and level of modernisation was not significant, F (1,35)= 1.22, n.s.

Interaction Effects

Three interaction effects were found significant. The length of time it took to name each of the four bills varied significantly with selling practice, F (3,105) = 5.826, p = .001, and with level of modernisation, F (3,105) = 6.01, p = .001. Moreover, there was a significant three way interaction: naming times for the different types of bills interacted with selling practice and level of modernisation, F (3,105) = 5.59, p = .001. Since the three way interaction is significant, post hoc tests which assessed whether there were differences in the naming times for each of the bill types within each of the four groups were conducted. Tukey HSD posthoc tests were conducted to assess these within group differences (see Table 4 for the means). The Q critical value was set conservatively at the .01 level due to the large number of possible comparisons. The mean naming times for each stimulus type will be compared for each for the four groups. Four of these comparisons will be highlighted since they were predicted in the introduction. The second comparison, to be reported, is a direct test of the findings from Saxe's Bill and Numeral Identification study: 1) naming times for Standard Bills compared to Numeral Occluded Bills, 2) naming times for Numeral Occluded Bills compared to Currency Numeral Only Bills, and 3) naming times for Currency Numeral Only Bills compared to naming times for Non-Currency Numeral Only Bills, 4) the naming times for Standard Bills where the two Traditional and the two Modernising groups will be compared separately. The order in which the comparisons will be reported will parallel the speed in which the bills are named, with all groups naming Standard Bills faster, than Numeral Occluded Bills, which were in turn named faster than each of the Numeral Only bills.

Traditional Non-Sellers. Looking first at the Traditional Non-Seller group, results show that Standard Bills, ($\underline{M}$ = 825, $\underline{SD}$ = 54) were named significantly faster than Numeral Occluded Bills ($\underline{M}$ = 896, $\underline{SD}$ = 63), $\underline{Q}$ (3,105)= 4.27, $\underline{p} < .01$. The Numeral Occluded Bills were in turn named significantly faster than Currency Numeral Only Bills, ($\underline{M}$ = 1033, $\underline{SD}$ = 106), $\underline{Q}$ (3,105)= 8.37, $\underline{p} < .01$. Finally, Currency Numeral Only Bills were in turn named faster than Non-Currency Numeral Only Bills, ($\underline{M}$ = 1133, $\underline{SD}$ = 111), $\underline{Q}$ (3,105)= 6.08, $\underline{p} < .01$.

Interpreting the Standard and Numeral Occluded Bill comparisons, results indicated that the absence of numeral orthography significantly slowed down bill identification for the Traditional Non-Sellers, with Numeral Occluded Bills being named 71 msec slower than Standard Bills. Earlier it was hypothesised that Traditional groups would not show significantly slower Standard Bill compared to Numeral Occluded naming times. This prediction was based on the hypothesis that the absence of numeral orthography would not greatly slow down bill identification in Traditional groups with minimal school-based numeracy skills because both the ethnographic evidence presented here and Saxe's research, described earlier, suggest that this group emphasised the visuospatial features of the bill instead of the orthographic features. The current finding suggests that the orthographic features of a bill are tightly linked to the other visuospatial patterns of the bill. This finding does not suggest that visuospatial processes are emphasised over orthographic processes but rather, these sources of information are tightly linked for Traditional Non-Sellers. This finding is interpreted as showing an emphasis on contextualising literacy skills. Similar contextualising skills have been observed in anthropological accounts of Middle-Eastern literacy practices and in cognitive studies of deductive reasoning (Street, 1984; Wagner, 1994; Zebian & Denny, 1996).

The significant difference between Standard and Numeral Occluded naming can be compared to the even larger difference between Numeral Occluded and Numeral Only naming times (137 msec advantage for Occluded bills). This result suggests that the absence of the visuospatial properties of the bill even more dramatically slows down bill identification. The current view is that the visuospatial properties and the numerals are tightly interconnected, and it is when these interconnections are weakened, slightly weakened in Numeral Occluded naming and strongly weakened in Numeral Only naming, that bill identification is slowed down significantly. Together the findings reviewed here clearly show that Traditional Non-Sellers have highly contextualised bill identification skills. Continuing this line of reasoning, and highlighting the difference between Occluded and Numeral Only naming times, these findings secondarily show that speeded bill identification is slowed down even more significantly when numerals are presented outside of their familiar context. This finding was also observed among Saxe's sellers , but not his schooled non-sellers. Saxe attributed his finding to the influences of selling practice on numeral reading skills. However, the current findings show that unschooled non-sellers also have highly contextualised currency reading skills, suggesting that schooling experience also has an effect on the strength of the linkages between numeral orthography and bill context.

A third hypothesis was postulated in the introduction to the Bill and Numeral studies which can be assessed in the current analysis. Recall the hypothesis which stated that if an individual's number concepts are grounded in the currency system, compared to a written symbol system which was not limited to the particular numerical structure of a currency system, then the identification of Non-Currency Numeral Only Bills should be slower than the naming of Currency Numeral Only Bills. Results which showed significantly slower Non-Currency Numeral Only naming times in the Traditional Non-Seller group suggest that they have a currency-based representation of numerals used for currency. The present results suggest that non-sellers do not show this difference, however, since Traditional Non-Sellers were found to name Currency Numeral Only Bills faster than Non-Currency Numeral Only Bills; selling practice does not seem to explain these results. Furthermore, since none of the other three groups shows this difference, as we will see shortly, it is necessary to consider why this difference is significant only in the Traditional Non-Seller group. We can rule out the possibility that the Traditional Non-Sellers could not read the Non-Currency Numeral Only Bills because they were given the bills before the testing session to practice them. All participants correctly named the value of each Non-Currency Numeral Only Bill before they were administered the timed task. Moreover, looking at their error rates in Appendix J, there was no evidence for unusually high levels of error for Non-Currency Numeral Only Bills compared to Currency Numeral Only Bills. Ruling out this possibility, it seems likely that Traditional Non-Sellers', most of whom were homemakers who rarely see numerals except in the context of bills, had numeral reading skills which were limited to those numerals that appear on bills. This result reveals that individuals who have minimal levels of experience reading numerals outside the context of currency are very poor at reading numerals that are not currency-based.

The fourth comparison that was made was a between subjects comparison. In the review to the Bill and Numeral study, I predicted that Traditional Sellers will have faster Standard Bill naming times compared to Traditional Non-Sellers. The results of this comparison will be reported once the within subjects comparisons for the Traditional Seller group have been reported.

Traditional Sellers. Turning to the Traditional Sellers group, they showed the same pattern of results as the Traditional Non-Seller group except that Currency Numeral Only Bills were not named significantly faster than Non-Currency Numeral Only Bills. Presenting the results of each comparison, the Traditional Seller group named Standard Bills, (M = 724, SD = 46) faster than Numeral Occluded Bills

(M = 797, SD = 72), Q (3,105)= 4.45, $p < .01$. Numeral Occluded Bills were in turn named faster than Currency Numeral Only Bills, (M = 871, SD = 94), Q (3,105)= 4.51, $p < .01$, and Non-Currency Numeral Only Bills, (M = 865, SD = 54), Q (3,105)= 4.14, $p < .01$. The comparisons show that the Traditional Seller group, like the Traditional Non-Seller group, have highly contextualised representations of numerals. Since the Traditional Sellers also show highly contextualised numeral reading skills, it can be concluded that level of modernisation and not selling practice per se gives rise to these skills. When collapsing across selling practice the level of modernisation grouping variable amounts to a level of education variable. Thus these findings will be taken as evidence that low levels of school-based numeracy practices are associated with high levels of contextualised bill identification and numeral reading skills. This interpretation of the results finds support in cross-cultural cognitive style research, and in anthropological research interpreted with the cognitive style framework, which shows high levels of contextualised thinking in Middle-Eastern and other non-Western cultural groups (Heath, 1983; Zebian & Denny, 1996). These cognitive style preferences contrast with the high levels of decontextualised thinking observed in Western groups (Davis & Denny, 1989; Chafe & Danielewicz, 1987;

Fernandez, 1980; Heath, 1983; Turner, Denny, Berry, & Bennett, 1993; Zebian & Denny, 1996). Evidence for a contextualising style is also observed in Middle-Eastern literacy practices which emphasise how print looks in its surrounding context, and de-emphasise of the skills involved in making meaning out of words presented in isolation, that is words presented outside a visuospatial context, and more broadly, written texts that function independently of social considerations that arise out of everyday practices (Street, 1984; Wagner, 1993).

The final comparison to be reported for Traditional Sellers is the Currency Numeral Only and Non-Currency Numeral Only naming times. The 6 msec difference between the naming times in the Currency Numeral Only (M = 871, SD = 94) and the Non-Currency Numeral Only conditions was not significant (M = 865, SD = 54), Q (3,105) = 0.371, n.s. Comparing this result to those of the Traditional Non-Seller group, these results indicate that only the Traditional Non-Sellers are especially slowed down by Non-Currency numerals. Traditional Sellers, unlike Traditional Non-Sellers, have more experience reading numerals outside the context of currency transactions. For example they must read quantities on boxes, and they read tally sheets which itemize customer credits. It seems that this level of numeral reading outside the context of currency transactions gives them enough practice with non-currency-based numerals that they show no difference in the time it takes to name Currency and Non-Currency Numeral Only stimuli.

Standard Bill naming times for Traditional Sellers and Non-Sellers. The final prediction concerning the Traditional groups required a between-subjects comparison. For this hypothesis the Standard Bill naming times for Traditional

Sellers and Non-Sellers was compared. Results of post hoc test showed that Traditional Sellers named Standard Bills (M = 723, SD = 46) faster than Traditional Non-Sellers (M = 825, SD = 54), Q (3,105) = 3.79, $p < .05$. This results extends the results past research on the relationship between level of expertise and recognition speed for complex spatial patterns, faces, and word. It shows that the relationship between level of expertise or exposure also holds for familiar objects such as currency (Charness, 1991; Chateau & Jared, 2000; Gauthier, Tarr, Anderson, Skudlarski, & Gore, 1999; Gauthier, Williams, Tarr, Tanaka, 1998). The current findings show that Traditional Sellers who are more experienced with currency recognise bills faster than Traditional Non-Sellers who have less exposure with currency. These results will also be reported for the two Modernising groups, once the within-subject comparisons have been reported.

Modernising Non-Sellers. The Modernising Non-Sellers, like the two Traditional groups, showed faster Standard Bill naming (M = 774, SD = 74), compared to Numeral Occluded Bill naming, (M = 849, SD = 87), Q (3,105)= 4.57, $p < .01$. However, unlike the Traditional groups, Occluded bills were not named significantly faster than Currency Numeral Only Bills (M = 908, SD = 108), Q (3,105)= 3.57, n.s. Continuing on with the comparisons between Numeral Occluded and Non-Currency Numeral Only Bills, results showed that Occluded Bills were named significantly faster than Non-Currency Numeral Only Bills, (M = 916, SD = 122), Q (3,105)= 4.060, $p < .01$. Finally, in contrast to the Traditional Non-Seller group, Currency Numeral Only Bills were not named significantly faster than Non-Currency Numeral Only Bills, Q (3,105)= .481, n.s. Together these findings show that Modernising Non-Sellers, like Traditional Sellers and

Non-Sellers, identify bills significantly slower when numerals are not presented. However, the degree to which the Modernising Non-Sellers are slowed down does not increase significantly when the visiospatial context is not available, as shown by the non-significant difference between Numeral Occluded and Currency Numeral Only naming times. This finding shows that the Modernising Non-Sellers have less difficulty, compared to the Traditional groups, reading numerals presented without the bill context. This result is also observed in the Modernising Seller group, to be reported next, and therefore its implications will be discussed once the findings from the Modernising Seller group are reported.

Modernising Sellers. The Modernising Seller group, similar to all three groups reported on above, showed faster Standard Bill, (M = 670, SD = 67), compared to Numeral Occluded Bill naming, (M = 739, SD = 77), Q (3,105) = 4.00, $p < .01$. Similar to the Modernising Non-Seller group, Modernising Sellers did not show a significant difference in Numeral Occluded and Currency Numeral Only naming times, (M = 803, SD = 79), Q (3,105)= 3.67, n.s. Nor was there a significant difference between Currency and Non-Currency Numeral Only naming (M = 807, SD = 91), Q (3,105)= .225, n.s. showing that their recognition of non-currency based numerals is not slower than their recognition of numerals that represent monetary values.

Together the findings from both Modernising groups and the Traditional groups suggest that level of modernization and not selling practice account for how well these groups read decontextualised numerals. According to these findings, the Modernising groups do not show the high levels of contextualised numeral identification processes observed in the Traditional groups. The current results suggest that schooling experience and not Traditional vs. Modernising selling practices account for these robust differences. This finding is also suggested in Saxe's (1991) research, although he did not employ an orthogonal design to separate the effects of selling practice from level of schooling on numeral reading skills. Nevertheless, since his candy sellers were unschooled or only received very low levels of schooling, similar to our two Traditional groups, it seems reasonable to conclude that Saxe's findings also show that school-based numeracy practices give rise to more decontextualised numeral reading skills. This interpretation of the results finds further support when the results of the highly decontextualising University Euro-Canadian group are integrated. Recall that Euro-Canadians showed even higher levels of decontextualising numeral reading skills since there was a non-significant difference between the naming times for Standard Bills compared to Numeral Only bills. This difference was significant when we considered all four Lebanese groups together. Further evidence for high levels of decontextualised numeral reading skills among the Euro-Canadians was the finding that Numeral Only bills were named significantly faster than Numeral Occluded Bills. This difference was not observed in the two highly contextualising Traditional groups. In fact, the opposite result was observed; Numeral Occluded Bills were named significantly faster than Numeral Only Bills. Moreover, in both Lebanese Modernising groups the Occluded Bills were named slightly but not significantly faster than the Numeral Only bills, suggesting lower levels of decontextualising thinking compared to the Euro-Canadian group. In conclusion, it seems that higher levels of Western-style schooling give rise to decontextualised numeral reading skills, and exclusive experience of such schooling results in the highest level of decontextualised numeral reading and bill recognition processes.

Standard Bill naming times for Modernising Seller and Non-Seller groups. The final prediction concerning the Modernising groups, required a between-subjects comparison. The naming times for Standard Bills was compared for Modernising Non-Sellers and Sellers. Results of a post hoc analysis showed that Modernising Sellers named Standard Bills ($M = 670$, $SD = 66$) faster than Modernising Non-Sellers ($M = 723$, $SD = 46$), Q (3,105) = 3.9, $p < .05$. This result parallels that observed in the Traditional group and further showed that experience with currency is related to bill recognition speed. This finding is especially notable because each of the two Modernising groups, more so than the two Traditional groups, have high levels of experience with currency. In comparison to the Modernising groups, the Traditional Non-Sellers had very low levels of experience with currency compared to the Traditional Seller group. Thus it seems that even more subtle differences in levels of experience result in recognition time differences. This finding for familiar objects such as currency, once again corroborates findings which show the influences of skill on complex chess pattern recognition, novel object recognition and word recognition (Charness, 1991; Chateau & Jared, 200; Gauthier, Tarr, Anderson, Skudlarski, & Gore, 1999; Gauthier, Williams, Tarr, Tanaka, 1998).

Results for Large Number Concept Priming Study

Study 2b

Numeral Occluded and Currency Numeral Only Priming Analysis

In addition to assessing bill recognition, the data from the Bill and Numeral Recognition task were analyzed as a priming study to investigate whether number concepts were linked to the visual appearance of a bill. A priming effect arises when there is an improvement in processing created by an earlier experience. Thus if a number concept's pattern of activation is related to or overlaps with the pattern of activation for a second concept, then higher amounts of priming should result.

Two types of priming were investigated in the present study. In the Numeral Occluded priming condition, the length of time it took to name Standard Bill targets when they were preceded by related and unrelated Numeral Occluded primes was compared. For the second prime type, the Numeral Only priming condition, the length of time it took to name Standard Bill targets when they were preceded by related and unrelated Numeral Only prime was compared. A 2 (related vs . unrelated) x 2 (Numeral Occluded Prime type vs. Numeral Only Prime type) x 2 (Seller vs. Non-Sellers) x 2 (Traditional vs. Modernising) analysis of variance was conducted. The means for this analysis are reported in Table 5. Inspecting Table 5 while anticipating the results of the analysis of variance, the pattern of means shows high levels of Numeral Occluded priming in all groups, while Numeral Only priming is not observed in the Traditional groups and only observed to a variable degree in the Modernising groups, most notably in the Modernising Seller group.

Table 5

Large Number Concept Priming Study: The mean length of time in milliseconds it takes to name a Standard Bill preceeded by a related and unrelated Numeral Occluded Prime Type and Currency Numeral Only Prime Type

Groups		Numeral Only Priming	Numeral Occluded Priming
Traditional Non-sellers (n=10)	related primes	848 (67)	800 (92)
	unrelated primes	824 (71)	819 (55)
	Priming Effect	-24	-19
Traditional Seller (n=10)	related primes	749 (43)	675 (52)
	unrelated primes	731 (47)	745 (70)
	Priming Effect	-18.02	-70*
	Mean Related Prime	798 (47)	738 (56)
	Mean Unrelated Prime	777 (47)	782 (47)
	Mean Priming Effect	-21.07	-45
Modernising Non-sellers (n=10)	related primes	774 (81)	750 (100)
	unrelated primes	784 (68)	789 (75)
	Priming Effect	-10	-39*
Modernising Sellers (n=9)	related primes	664 (66)	639 (63)
	unrelated primes	695 (80)	680 (67)
	Priming Effect	-31*	-41*
	Mean Related Prime	719 (49)	695 (58)
	Mean Unrelated Prime	739 (49)	735 (48)
	Mean Priming Effect	-20	-40

* significantly faster naming times for the related compared to the unrelated condition as assessed by simple main effect tests (*p* < .05)

Main Effects

Overall, the related-unrelated main effect was significant. Standard Bill targets ($\underline{M}$ = 737) that were preceded by a related bill prime, regardless of whether they were preceded by a Numeral Occluded or Numeral Only Bill prime, were named significantly faster than unrelated Standard Bill targets, ($\underline{M}$ = 759), $\underline{F}$ (1,35)= 6.17, $\underline{p}$ < .01.

Turning to the within-subjects main effects which did not involve priming, the length of time it took participants to name Standard Bill targets that were preceded by Numeral Occluded and Numeral Only Bills, collapsing across the related vs unrelated effect and collapsing across the two between-subjects effects of selling practice and level of modernisation, showed that Standard Bill targets preceded by Numeral Occluded Bills, ($\underline{M}$ = 737) were named faster than Standard Bill targets preceded by Numeral Only Bills, ($\underline{M}$ = 759) $\underline{F}$ (1,35)= 14.77, $\underline{p}$ < .001. These results are not theoretically significant and therefore will not be discussed further.

The between-subjects main effects concerned selling practice and level of modernisation. The selling practice effect was significant. Sellers responded faster to all stimuli ($\underline{M}$ = 697) compared to Non-Sellers, ($\underline{M}$ = 799), $\underline{F}$ (1,35)= 27.21, $\underline{p}$ < .01. The level of modernization effect was also significant; Modernising groups ($\underline{M}$ = 722) named bills faster than Traditional groups, ($\underline{M}$ = 774), $\underline{F}$ (1,35)= 7.13, $\underline{p}$ < .05. The selling and level of modernisation main effects observed here were also observed in the recognition study.

Between-Subjects Interaction

The selling practice x level of modernisation effect was not significant, $F(1,35) = .028$, n.s. These result show that selling practice and level of modernisation are additive and not interactive factors in the priming study, although they were shown to be interactive in the recognition study. To get a sense of why selling practice and level of modernisation are additive factors in the priming study, we need to consider the strength of the priming results for each priming type for all four groups. Looking at the pattern of priming in table 5, and for a moment laying aside which priming results are statistically significant, we see that the level of modernisation and the selling practice variables are additive for two reasons. First, Numeral Occluded Priming is strong in three of the four groups, Traditional Sellers, Modernising Non-Sellers, and Modernising Sellers. The second reason that the two between subjects factors are additive is because Numeral Only Priming, as we will see shortly, is only observed in the Modernising Seller group. Consequently, it is the high levels of Numeral Occluded Priming and the very low levels of Numeral Only priming that give rise to these additive effects. It is difficult to draw general conclusions about the relationship between level of modernisation and selling practice independent of the current pattern of results. However, for Numeral Occluded and Numeral Only priming, the current result show that level of modernisation accounts for most of the variability in priming results, while selling practice seems only to account for Numeral Only priming in groups who generally do not show Numeral Only priming.

2-way Interactions.

Only one of the possible six 2-way interactions was found significant. The Occluded vs Numeral Only Prime type by Related vs. Unrelated factors interacted significantly, F (1,35) =16.137, $p < .001$. For Numeral Only priming, Standard Bill targets which were preceded by related Numeral Only bills (M = 758.8, SD = 79) were named as fast as targets preceded by an unrelated prime (M = 758.3, SD = 66). Turning to Numeral Occluded Priming, Standard Bills primed by a related Numeral Occluded Bills (M = 715, SD = 65) were named faster than targets primed by an unrelated Numeral Occluded bill, (M = 758, SD= 66). These results show that there was no overall Numeral Only priming effect but there was a sizable Numeral Occluded priming effect. Follow-up post hoc tests were not conducted to assess which mean differences were significant since there was a significant three way interaction with these means and the level of modernisation factor, which will be reported next. See Appendix L which summarises the analysis of variance results, for the other five 2-way interactions that did not reach significance.

3-way Interactions

One of the four possible 3-way interactions was found significant. The Numeral Occluded-Numeral Only Priming type factor interacted with the Related-Unrelated factor and the Level of Modernisation factor, F (1,35) = 4.482, $p < .05$. The means in Table 5 suggest that the levels of Numeral Only Priming observed in the Modernising groups but not in the Traditional groups may be driving the interaction. Follow-up Tukey HSD post hoc tests were conducted to unpack the results of the significant interaction. Recall that two predictions were put forth in the introduction to the Large Number Concept Priming study. These predictions were that Traditional Sellers would show the highest level of Numeral-Occluded priming. Second, that Modernising Sellers would show the highest level of Numeral Only priming. Post hoc tests show some support for these predictions which posit that selling practice and level of modernisation, together affect number conceptualisation. This statement is, however, made cautiously since the four way interaction, which will be reported below, showed a non-significant trend in the predicted direction.

Looking first at Numeral Only priming and looking at the Traditional group first (Seller and Non-Seller groups combined), results show that Standard Bill targets preceded by Related Numeral Only Bills, ($\underline{M}$ = 798, $\underline{SD}$ = 47), were not named significantly faster than Standard Bill targets preceded by Unrelated Numeral Only Bills, ($\underline{M}$ = 777, $\underline{SD}$ = 47), $\underline{Q}$ (60.6) = 1.58, n.s. In fact there was a non-significant trend in the opposite direction of priming. Results from the Modernising group (collapsing across selling practice) showed a trend in the predicted direction however, it did not reach significance. Standard Bill targets primed by Related Numeral Only primes, ($\underline{M}$ = 719, $\underline{SD}$ = 49) were not named significantly faster than Standard Bill targets primed by Unrelated Numeral Only primes, ($\underline{M}$ = 739, $\underline{SD}$ = 49), $\underline{Q}$ (60.6) = 1.48, n.s. Although a Numeral Only priming effect was not observed in the Modernising groups when means were collapsed across the two selling groups, an inspection of the priming effects for each group (see Table 5) indicates that only the Modernising Sellers show a sizable Numeral Only priming effect. Consequently, two planned comparisons, using the Tukey HSD post hoc procedure, were conducted to separately assess whether the Modernising Seller and the Modernising Non-Seller groups showed Numeral Only priming. Looking first at the Modernising Seller group, Standard Bill targets primed by related Numeral Only Bills ($\underline{M}$ = 664, $\underline{SD}$ = 66) were named significantly faster than Standard Bill targets primed by Unrelated Numeral Only Bills, ($\underline{M}$ = 695, $\underline{SD}$ = 80), $\underline{Q}$ (60.6) = 2.87, $\underline{p}$ =.05. The priming effect was not significant for Modernising Non-Sellers, $\underline{Q}$ (60.6) = 1.37, n.s.

The results of the Numeral Only priming planned comparisons showed that Numeral Only Bills, which are monetary values without a bill context, prime Standard Bills only for Modernising Sellers. This finding was interpreted as showing that monetary values prime the whole bill concept. This finding fits with the findings from the recognition which revealed higher levels of decontextualised numeral recognition skills in Modernising Sellers. Together the priming and recognition findings showed that standard numeral orthography and not only the bill context, play an important role in the way number concepts are conceptualised by Modernising Sellers whose numeracy practices involve monetary values outside the context of currency. Turning to the Traditional groups, Numeral Only priming is not observed in the Traditional groups since the linkages between the monetary value of the bill and the bill contexts are so tightly connected that a monetary value presented without a bill context will not prime a standard bill. These priming results further support the recognition results which showed Traditional groups to have highly contextualising number concepts where the value of a bill is strongly linked to its visuospatial properties. Turning to the Modernising Non-Seller group who did not show significant levels of Numeral Only priming, their results suggest that a numeral presented in isolation, which instantiates a monetary value, does not prime a standard bill of the same value. This is likely to be the case because Modernising Non-Sellers have less experience thinking about the linkages between numbers and currency-based monetary values. This is a skill that seems to develop specifically out of Modernising Selling practices which require sellers to use numbers in the context and outside the context of currency use. Considering how the priming and recognition results are related for the Modernising Non-Seller group, it will be argued the recognition results show they have decontextualised representations of numerals, but these representations are not strongly associated with monetary values. The implications of the findings from both the Recognition and Priming analyses for models of number conceptualisation will be reviewed in the General Discussion. Next, we turn to the Numeral Occluded priming results.

Looking first at the Traditional group (seller and non-seller groups combined) and comparing Related and Unrelated Means for the Numeral Occluded Priming type, results showed that Standard Bill targets primed by Related Numeral Occluded Bills(M = 738, SD = 56) were named significantly faster than Standard Bill targets primed by Unrelated Numeral Occluded Bills, (M = 782, SD = 47), Q (60.6) = 3.28, p < .05. Turning to the Modernising group, Standard Bills primed by Related Numeral Occluded Bills (M = 695, SD = 58) were also named significantly faster than Standard Bills primed by Unrelated Numeral Occluded Bills, (M = 735, SD = 48), Q (60.6) = 2.98, p < .05.

As a follow-up to the level of modernisation effect for the Numeral Occluded priming results, planned Tukey HSD posthoc tests were conducted to assess whether Numeral Occluded priming was observed in each of the four groups since the level of priming varies considerably, as observed in Table 5, with the Traditional Seller group showing the highest level of priming with 70 msec priming effect and the Traditional Non-Seller group showing a relatively small 19 msec advantage for related Numeral Occluded priming. Looking at the priming effect separately within each of the four groups, results showed significant levels of priming in the Traditional Seller group; Standard Bill targets preceded by a related Numeral Occluded Bill prime,

(M = 675, SD = 52), were named significantly faster than Standard Bills preceded by unrelated Numeral Occluded Bills, (M = 745, SD = 70), Q (60.6) = 5.212, $p < .05$. Significant levels of priming were also observed in the Modernising Non-Seller group, Standard Bills targets were named significantly faster when they were preceded by a related Numeral Occluded Bill, (M = 750, SD = 100) compared to an unrelated Numeral Occluded Bill prime, (M = 789, SD = 75), Q (60.6) = 2.9, $p < .05$. Finally, a significant level of priming was also observed in the Modernising Seller group; Standard Bills preceded by related Numeral Occluded primes (M = 639, SD = 63) were named significantly faster than those preceded by unrelated Numeral Occluded primes (M = 680, SD = 67), Q (60.6) = 3.10, $p < .05$. A non-significant level of Numeral Occluded priming was observed in the Traditional Non-Seller group, Q (60.6) = 1.36, n.s. The results of these exploratory analyses suggest that Standard Bill naming times for the Traditional Non-Seller group, the group with least experience with currency, were not significantly primed by

Numeral Occluded Bills. The Traditional Sellers, Modernising Sellers and Non-Sellers who have most experience with currency show significant levels of Numeral Occluded priming. It is also significant to note that the highest level of priming was observed in the Traditional Seller group, which were also shown above to have highly contextualising bill and numeral identification skills. This high level of priming is further evidence that the body of a currency bill serves as a psychologically significant context for the conceptualisation of numerals in Traditional Seller groups.

4-way interaction. The Numeral Occluded-Numeral Only Prime type x Related-Unrelated x level of modernisation x selling practice interactions approached but did not reach significance, F (1,35) = 2.27, p = .14. This result shows that selling practice does not significantly account for additional variability in the priming results. Nonetheless, these results are understandable since only the Traditional Non-Seller group, but not the Modernising Non-Seller group, showed no Numeral Occluded priming.

Discussion Study 2b

Currency Use, Selling Practices and Numeric Processes: Implications for Theories of Number Conceptualisation

The current findings from the series of Bill and Numeral Studies make some substantial contributions to our understanding of how currency, as a cultural artifact in selling practice, shapes number conceptualisation. The results of the recognition study and the priming study, show that the numeracy practices of Traditional Sellers which involve orally-based numeric skill emphasise the development of highly contextualised number concepts. The numeracy practices of Modernising Sellers, which involve reading and writing monetary values outside the context of currency, lead to the development of decontextualised numeric skills. The current findings are suggested in Saxe's research, which showed that sellers compared to schooled non-sellers are less skilled with decontextualised numeric processes such as orthographically based numeral reading. Adding to this, for the first time the current finding shows that Traditional groups have contextualising numeric skills, and that Traditional selling experience leads to strong currency based representations. Moreover, these findings are consistent with ethnographic observations of maths in practice which revealed linkages between orally-based math skills in Traditional groups and contextualising recognition and conceptualisation skills. Furthermore, the linkage between literacy-based maths skills and decontextualising representation is observed in Modernising groups. In sum, the findings of the current study showed, for the first time, that artifacts and socially embedded numeracy practices provide psychologically real contexts that lead to the development of qualitative differences in automatic processes of number conceptualisation and recognition. The implications of these findings for models of number processing will be taken up in the general discussion.

General Discussion

The main purpose of the SNARC studies was to investigate whether the linkages between numeric and spatial processes are modified by the directionality of the Arabic right-to-left writing system. The Currency as Artifact in the Maths of Selling Practice studies investigated whether the numeracy practices of Traditional and Modernising Lebanese Sellers influence the development of different numeral and bill recognition skills and number conceptualisation processes. Empirical research which shows how these necessary linkages between automatic numeric and non-numeric cognition are shaped by artifact use is very sparse. The current series of studies contribute to the empirical research which shows that numeric processes are shaped and modified by non-numeric processes. Furthermore the current investigations suggest that artifact use and socially situated numeracy practices lead to the development of these linkages.

Review of Reverse SNARC Effect Findings

The main findings from the SNARC studies show that numbers are conceptualised as points along an analogical number line, which seems to exploit the same spatial dimension as one's reading and writing system. In the Oral Numeral Only SNARC study, it was shown, for the first time, that Arabic Monoliterates who use a right-to-left writing system think about numbers as starting from the right and increasing in magnitude to the left. This effect has been coined, in the present investigation, the Reverse SNARC effect. This finding supports Dehaene et al.'s (1993) hypothesis that the number line takes on the same spatial properties as one's writing system. This hypothesis is further supported by the finding from the Illiterate Lebanese group which does not show a Reverse SNARC, revealing that motor skills of reading and writing in a right-left direction and not simply being immersed in a literate culture that displays numbers from right to left influences how numbers are organised on a number line. Further extending our understanding of the influences of directionality of writing on number conceptualisation, the results from the Adult

Biliterate group, which show only a trend towards the Reverse SNARC, suggest that the biliterates' native Arabic right-to-left writing system still has an influence over number conceptualisation. These influences from Arabic writing are even stronger in the Child Biliterate group who show a Reverse SNARC. The evidence for a Reverse SNARC in biliterate children who have only begun to learn English suggested that high levels of English second language skill is required before the Reverse SNARC is weakened. This interpretation of the results from the Child and Adult Bilingual groups corroborate Dehaene et al.'s (1993) findings which showed that Persian-French biliterates with strong French language skills show a stronger SNARC effect compared to biliterates less skilled in French. It can be concluded from the current and past research, that the tendency to spatialised numbers from right-to-left, which is influenced by right-to-left literacy, is weakened more if the opposite left-to-right reading skills are strong, and weakened less if left-to-right language skill is weak. These converging lines of evidence which show a relationship between level of second language skill and strength of the directionality of the spatialisation effect, nevertheless need to be followed up with research which more precisely assesses level of second language skill. In the current investigation the self report measure of number of years of bilingual education was used to separate bilinguals from monolinguals. This remote measure does not capture gradients in level of second language skill, which Dehaene et al. show predict the strength of the SNARC effect. A more direct measure of second language skill, such as an ESL (English-as-a Second Language) reading comprehension test, is required before we can more directly assess the relationship between levels of left-right language skill and the strength of the Reverse SNARC.

Influences of directionality of writing on number conceptualisation. Dehaene offers a rudimentary explanation for why the directionality of writing affects number conceptualisation. He postulates that the SNARC effect seems to reveal a natural mapping of the numerical continuum onto the extracorporeal physical space (Dehaene, 1992). He notes that people have daily experiences with numbers organised along a left-right physical continuum. For example numbers are organised from left to right on rulers, calendars, typewriters, and in elevators. Dehaene does not offer an explanation as to why there are these mappings between the spatial organisation of numbers in the world and an internal number line. However, Lakoff (1987) in his embodied theory of concepts, argues that abstract concepts, such as numbers, arise out of and are tied directly to the structural aspects of bodily experience in the world. According to Lakoff, embodied perceptuo-motor concepts provide an experiential basis for understanding magnitude. Directionality of writing and other literacy practices which involve left-right perceptuo-motor processes could constitute experiences that give structure to the number line. Although this is a preliminary attempt to explain why writing influences number conceptualisation, there remain other puzzling issues concerning its influences since the East Arabic numerals themselves have a left-to-right order. For example the East Arabic numeral ٥١ (51), appears in a left-to-right order with the decade digit 5 appearing to the left of the units digit 1, as it would in International Arabic numeral notation. However, the order in which the numerals 5 and 1 are written down on a page follows a right-to-left ordering, such that the East Arabic digit 1 is written first and the decade digit 5 is written second, that is, to the left of the units digit. Moreover, when the number "51" is spoken in Arabic, it is spoken as *one plus fifty*, thus the way it is spoken parallels the right-to-left order in which the digits are written. It is not clear whether the motor processes and the corresponding conceptual processes involved in this specific number notation system strengthens or weakens the right-left spatialisation of number concepts. Speculating on these influences it may be the case that the left-right orientation of East Arabic Numerals may partly limit the independent influences of a right-to-left writing system on number conceptualisation.

SNARC effect as assessed in same-different judgement tasks in English Monoliterate Groups

The two main findings from the English Monoliterate groups were the failure to find a significant SNARC effect for numeral numeral judgements and the finding of a significant SNARC effect only in the number word-numeral condition. There is some discrepancy between these findings and the findings from Dehaene and Akhavein's (1995) study where they observed a significant SNARC that did not vary significantly across the four notation conditions. It is however, difficult to make strong conclusions from Dehaene and Akhavein's study since there was a methodological problem (discussed above) which biased participants to make perceptually-based, as opposed to conceptually-based, judgements. Moreover, strong conclusions from Dehaene and Akhavein's study are not warranted since the results were based on the performance of only nine subjects. With these considerations, as well as the current findings from the Oral

Numeral Only (Study 1a), Bimanual Replication (Study 1d), and Oral Version of the Replication studies (Study 1e), it is concluded that the SNARC effect is revealed only under conditions where the stimulus strongly invokes a left-right number line. This interpretation finds some support in the past research, reviewed above, which clearly showed that the strength of the SNARC effect varies depending on the task. A stronger effect is observed in numerical judgement tasks which more directly invoke a number line compared to parity judgement tasks that do not demand linear magnitude judgements (Brysbaert, 1995; Dehaene et al., 1993; Dehaene, Dupoux, and Mehler,1990). This interpretation suggests that the SNARC effect is very sensitive to contextual effects. Bachtold, Baumuller, and Brugger's (1998) research provides an especially good example of this context sensitivity. Recall that when participants were instructed to invoke the visual image of a ruler during a numeric judgement task, they showed a strong SNARC while the SNARC effect was eliminated when the non-linear spatial image of a clock was invoked. Together the current findings which reveal the SNARC effect in number word-numeral conditions and past findings which show a stronger effect in numeric comparison tasks, suggest that the activation of a left-right number line must be supported contextually.

The findings from several past studies using different numeric judgement tasks suggest that the left-right spatialisation of the number line may arise out of culturally specific writing experiences. However, the current evidence also shows that the SNARC effect, as it is assessed in the same-different judgement task, must also be strongly invoked in specific contexts where the linear spatialisation of numbers is needed to meet task demands. Follow-up research employing an oral same-different judgement task which more directly assesses magnitude representation is required before stronger claims about the SNARC effect can be made.

Review of Bill and Numeral Study

There were three main findings from the Bill and Numeral Recognition Study and the Large Number Priming Study. From the Recognition Study, Traditional Sellers and Non-Sellers were shown to have highly contextualising bill and numeral recognition skills such that a numeral was recognised much more quickly when presented in the context of a currency body in comparison to when it was presented without a body context. In comparison to the Traditional groups, the Modernising groups showed a greater emphasis on decontextualised bill and numeral recognition processes as evidenced by their Numeral Only naming times which were comparable to their Numeral Occluded naming times. Turning to the Euro-Canadian group, they showed even higher levels of decontextualised bill and numeral recognition, as their Numeral Only naming times were comparable to their Standard Bill naming times, and significantly faster than their Numeral Occluded naming times. The second main finding from the Large Number Concept study, was that the groups with most experience with currency, that is the Traditional Sellers, Modernising Sellers, and Modernising Non-Sellers, showed Numeral Occluded priming. The third main finding, also from the Large Number Concept Priming study, was that only the Modernising Sellers showed Numeral Only priming.

The findings from the Bill and Numeral Study significantly advance our understanding of how artifacts used in the maths of selling practice affect numeric processes. Beginning with the relevance of the recognition portion of the study to Saxe's research, the current findings support Saxe's ethnographic and survey research, and his off-line Bill and Numeral Identification study all of which indirectly suggest that sellers have a currency-based representation of large numbers. Saxe's research did not directly and empirically show the currency-based representations of sellers, but rather his findings showed what they do not do well, i.e., recognise numerals apart from a bill context. From these findings Saxe concluded that sellers compared to schooled non-sellers emphasised visuospatial bill recognition processes while schooled non-sellers emphasise orthographic processes. The results of the current study offer direct evidence which provides a more complete understanding of these automatic recognition skills. Specifically, the finding from the current Bill and Numeral Recognition study which showed that all groups named Standard Bills slower than Numeral Occluded Bills, does not suggest that visuospatial processes per se are being emphasised. If the visuospatial properties were being emphasised at the expense of orthographic processes, results would have shown a non-significant differences in the time it took Traditional groups to name the Standard Bill compared to the Numeral Occluded Bill. The reason being that the absence of numeral orthography would not have greatly slowed down identification process if they were primarily driven by visuospatial feature processing. We did not find these results. Rather, Standard Bills were named significantly faster by all Lebanese groups. These results are taken as evidence that the orthographic and the visuospatial properties of the bill are tightly connected, such that the visuospatial properties of the bill are a context for the numerical value. Once this point is established, secondarily, it may be argued that the visuospatial processes are emphasised more than the orthographic processes in highly contextualising Traditional groups (Zebian & Denny, 1996). This interpretation is further reinforced in the findings which show very slow Numeral Only recognition times in both the Traditional Seller and Traditional Non-Seller groups, but not in either of the two less contextualising Modernising groups, nor in the highly decontextualising Euro-Canadian group.

The second main finding from the recognition study is that Sellers named all bills faster than Non-Sellers and Modernising groups named bills faster than the Traditional groups. This finding reveals that more experience with currency leads to faster bill recognition. Thus it seems that recognition times even for familiar objects such as currency are influenced by experiential factors. This relationship between level of skill and recognition has also been observed for simple novel objects and complex chess patterns (Charness, 1991; Gauthier, Tarr, Anderson, Skudlarski, & Gore, 1999; Gauthier, Williams, Tarr, & Tanaka, 1998).

Adding to the findings from the recognition portion of the Bill and Numeral study, the priming results complement and show linkages between speeded recognition and number conceptualisation. The main finding showed that groups most experienced with currency, the Traditional Sellers, Modernising Non-Sellers, and the Modernising Sellers, showed Numeral Occluded priming. The Traditional Non-Sellers, eight of ten who are homemakers who had never been employed, did not show Numeral Occluded priming. This finding shows that the pattern of activation for the Numeral Occluded Bill significantly overlaps with the pattern of activation for a Standard Bill. The absence of numerical orthography does not seem to be slowing down processes significantly. This is why Numeral Occluded Bills facilitate the naming of a Standard Bill of the same monetary value among Traditional Sellers, Modernising Non-Seller, and Modernising Sellers. It is only when individuals do not have a lot of daily experience with currency, like the Traditional Non-Sellers, that Numeral Occluded Bills, which do not have numerical values on them, do not significantly prime Standard Bills. The Traditional Non-Sellers were not primed because the overlap in patterns of activation between an Occluded Bill, that does not have orthographic features, and Standard Bill is not as strong as it was for the other three groups. The Traditional Seller and the two Modernising group showed priming because the missing orthographic information may not have greatly disrupted their bill concept, whereas it may have been disruptive to Traditional Non-Sellers who have even stronger linkages between the visuospatial and orthographic features.

Turning to Numeral Only priming, results of exploratory post hoc tests revealed Numeral Only priming only in the Modernising Seller groups. Again the priming results complement and extend our understanding of the relationship between recognition and number conceptualisation. The recognition findings showed that the Modernising Sellers did not significantly slow down for Currency Numeral Only Bills compared to Numeral Occluded Bills. From this result, it was concluded that they had lower levels of contextual recognition skills, compared to the Traditional groups. The priming results extend these findings to show that not only are Modernising Sellers good at reading numbers in isolation, but numerals presented without visuospatial context activate currency-based number concepts. Since the visuospatial features of the bill are not required for activating the bill concept, it will be postulated that Numeral Only priming occurs because the numerical value of the Numeral Only bill, regardless of its context, activates the same numerical value activated by the Standard Bill. This level of priming does not occur for Traditional Sellers and Non-Sellers because there are stronger linkages between the particular notation of a currency concept and its numeric value. Furthermore, this level of priming may not occur for Modernising Non-Sellers since the numerical value of a numeral presented in isolation does not instantiate the numerical value activated by a Standard Bill among these people with less experience with money. It is likely that these specific linkages between orthographic monetary numerals and standard bills arise out of selling practices which require sellers to think about the relations between monetary values and currency, i.e., thinking about large quantities of items and their monetary value. The ethnographic findings, discussed above, showed that these are important skills in Modernising selling practices.

The current findings and implications for models of number processing. The findings of the recognition and priming studies make significant contributions to our understanding of the linkages between perceptual and conceptual numeric processes, and they further reveal that artifact use in the maths of selling practice has consequences for numeric processes. Both these findings support models which posit stronger linkages between perceptually-based notational encoding processes and conceptual processes. These views are posited most strongly in the encoding-complex model (Clark & Campbell, 1988;

Campbell, 1994) which claims that numbers are represented in terms of modality-specific mental codes which take on different forms, i.e., they may be phonological, orthographic, visuospatial, or perceptuo-motor. Campbell and Clark (1988) suggest that these linkages between notation specific codes and conceptual representations of numerals arise out of an individual's idiosyncratic learning history, culture-specific strategies, and other skill related factors. The findings of the current study clearly support this conclusion. The Traditional groups and the Modernising sellers not only show linkages between recognition and conceptualisation processes but each shows qualitative differences in each process. The current findings also directly challenge McCloskey's abstract amodal model which posits that recognition processes are not related to number conceptualisation. In the current investigation, the pattern of consistent findings between contextualising recognition skills and conceptualisation skill among Traditional groups, especially Traditional Sellers, and decontextualising recognition and conceptualisation skills among Modernising groups, challenges this view. Based on the current findings it will be suggested that notation-specific comprehension processes do not passively pass information to an amodal representation, but rather there are strong linkages between these two processes. These linkages may be partially modified by various socially-based numeracy practices. For example, school numeracy involves an emphasis on decontextualised numeric processes where the representation and use of numbers is not embedded in rich visuospatial contexts and is not directly linked to everyday practices which involve concrete objects or quantities (Lave, 1988). In the current investigation high levels of these skills were observed in our Euro-

Canadian group and in the Lebanese Modernising groups to a lesser extent. These decontextualised numeracy skills contrast sharply with highly contextualising orally-based numeracy skills of Traditional Seller and Non-Seller groups.

Artifact use in the maths of selling practice and implications for theories of number processing. One of the primary objectives of the current investigation was to study how automatic numeric processing is affected by artifact use in the maths of selling practice. This line of inquiry brings together processing and structural issues central to the three models of numeric cognition (discussed above) while maintaining the linkages to social constructivist approaches which try to account for mathematics naturalistically in a way which recognises everyday social practices. One of the main conclusions that can be drawn from the current Bill and Numeral study is that currency use shapes on-line numeric processes. The strongest evidence for this conclusion comes from the result which showed Numeral Only priming only in the Modernising Seller group. Although this result was revealed in exploratory simple main effect tests, it does suggest that both selling practice and modernisation account for Numeral Only priming. In further support of this conclusion, the results show no Numeral Only priming in the Traditional Seller and Non-Seller groups, nor in the Modernising Non-Seller groups. Thus it seems that the linkages between monetary values and currency units develops specifically out of Modernising Selling practices which require sellers to use numbers in the context and outside the context of currency use.

None of the three models of number processing, the encoding complex model, the abstract amodal model, and the triple code model, have developed frameworks for considering about how artifacts could influence number processing. The current findings together with Saxe's (1991) research and past research on abacus use suggest that the perceptuo-motor processes involved in artifact use strongly mediate and shape numeric cognition (Hatano, Amaiwa, & Shimizu, 1987; Hatta, Hirose, Ikeda, & Fukuhara, 1989; Hishitani, 1990; Stigler, 1984). Outside mathematical psychology, the view that artifacts place specific constraints on thought processes is held and empirically investigated by a growing number of researchers (Ascher, 1991; Hutchins, 1995a, 1995b; Keller & Dixon Keller, 1996; Goodwin, 1994; Goodwin & Harness Goodwin, 1996; Leont'ev, 1981; Saxe, 1982).

Frameworks for Cross-Cultural Studies of Mathematics

Research, which attempts the complex task of understanding what aspects of sensorimotor experience and cultural practice shape internal numeric processes, must be grounded in ethnographic observations of naturally-occurring quantitative thinking. This was precisely the recommendation of Michael Cole (1977) who pioneered cross-cultural studies of mathematics (Cole, Gay, Glick, & Sharp, 1971). Cole has strongly advocated the use of ethnographic methods in cross-cultural research for several reasons (Cole, 1977, 1996; Cole, Gay, Glick, & Sharp, 1971). He argued that ethnographic research allows psychologists to see the cognitive skills of other cultural groups not as deficits but as skills which arise to meet goal-directed and socially-situated demands. Moreover, he argues that ethnographic observations are required to construct culturally appropriate tasks that validly assess cognitive skills. Cole's early recommendations however, did not seem to be widely incorporated into cross-cultural maths studies, until relatively recently (Beach, 1995; Saxe, 1991; Millroy, 1991). In fact this has been a strongly counter-productive trend in the broader field of cross-cultural psychology, as discussed in great detail by Cole (1996) and by Hutchins (1995a). For various reasons, which are beyond the scope of the current discussion, cross-cultural cognitive psychologists have not proceeded with the task of coordinating ethnographic and experimental methods. The Bill and Numeral investigations provide one model for cross-cultural maths research where ethnographic observations are used to generate predictions which are then tested experimentally.

Grounding the study of mathematical thinking in ethnographic research is not a panacea for cross-cultural maths studies because ethnographic methods alone do not tell us what aspects of cultural practice and what aspects of the context will have consequences for cognition. Ethnographers who have conducted fieldwork and psychologists who study cognition in practice struggle with precisely the issue of understanding why aspects, features, or contexts have cognitive consequences (Scribner, 1986; 1990; Lave, 1988). Until relatively recently, cognitive science has offered very little in terms of frameworks for explaining why thought is so strongly situated. The new focus on embodied theories of cognition which emphasise the architectural linkages between thought, perception, and action also provide frameworks for thinking about everyday cognition where all these modes of thought are coordinated in cultural practices. One of the most comprehensive frameworks has been put forth by

Barsalou (1999).

Barsalou's perceptual approach to cognition offers a psychological explanation of why context matters for cognitive functioning. According to Barsalou, the building blocks of the conceptual system are perceptual symbols, neural representations in the sensorimotor areas of the brain, which represent schematic components of sensory and motor experience; they do not include holistic representations of sensory events. These perceptual symbols become organized into simulators that enable, through a simulation processes akin to mental imagery and mental modelling, the partial reconstruction of an event in its absence, although the content of this schematic representation remains to be discovered. The simulations preserve at least some aspects of our actual sensorimotor experiences. Barsalou also recognises that what gets represented in simulation routines develop to meet cultural demands, but this part of the proposal is left undeveloped. The main claim that thought is grounded in sensorimotor experience explains why cognitive functioning is strongly linked and arises out of everyday practice and features of the perceptual context. A cognitive science framework which emphasises processing issues and coordinates cultural approaches to mathematical thinking may will improve our attempts to understand what people actually do with numbers, what cognitive skills are involved in everyday quantitative and mathematical tasks, and how social life and artefact use shape quantitative thinking.

In the current investigations attempts have been made to bring together several approaches to everyday numeric cognition. The maths cognition theories, the social constructivist approach, and the cognitive psychological frameworks outlined here offer very diverse approaches to the study of everyday maths. They show considerable variability and variable success in their understanding of how thought is situated and what contexts matter for cognitive functioning. However, what is important to pioneering studies of everyday maths cognition is that these theoretical frameworks give rise to specific empirical questions about what people actually do with their minds, what cognitive skills are involved in task accomplishment, and how social life and artifacts shape thinking.

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Appendix A

Number of Errors, Non-trials, and Outliers for Oral Numeral Only SNARC Studies

	Errors	Non-trials	Outliers
Arabic Monoliterates (n=19)	50	65	29
Arabic-English/French Biliterates (n=17)	41	55	34
English Monoliterates (n=19)	19	15	26
Lebanese Illiterates (n=11)	23	30	26
Child Biliterates (n=8)	29	14	19

Appendix B

Analysis of Variance Table for Oral Numeral Only Study

Main Effects

Left-Right/ Right-Left	$F(1,50) = 2.494$, $p > .05$
Group	$F(1,50) = .867$, n. s.

Interaction Effect

Left-Right/Right-Left x Group	$F(1,50) = 3.168$, $p = .05$

Appendix C

<u>Analysis of Variance Table for Replication of Dehaene and Akhavein's Bimanual SNARC Study</u>

<u>Main Effects</u>

Left-Right/Right-Left	F (1,19) = 2.89, n.s.
Hand of Response	F (1,19)= .703, n.s.
Notation	F (3,57) = 64.06, $p < .001$

<u>2-way Interactions</u>

Hand of Response x Left-Right/ Right-Left	F (1,19) = 1.72, n.s.
Notation x Left-Right/Right-Left	F (3,57) = 1.20, n.s.
Hand of Response x Notation	F (3,57) = .889, n.s.

<u>3-way Interactions</u>

Hand of Response x Notation x Left-Right/Right-Left	F (3,57) = .886, n.s.

Appendix D

Follow-up Analysese to Replication of Dehaene and Akhavein's Bimanual SNARC Study

Right Handed Responses Only

Main Effects

Left-Right/Right-Left	F (1,19) = 4.14, p = .05
Notation	F (3,57) = 38.58, p < .001

Interaction Effects

Left-Right/Right-Left x Notation	F (3,57) = .726, n.s.

Left Handed Responses Only

Main Effects

Left-Right/Right-Left	F (1,19) = .450, n.s.
Notation	F (3,57) = 41.08, p < .001

Interaction Effects

Left-Right/Right-Left x Notation	F (3,57) = 1.48, n.s.

Appendix E

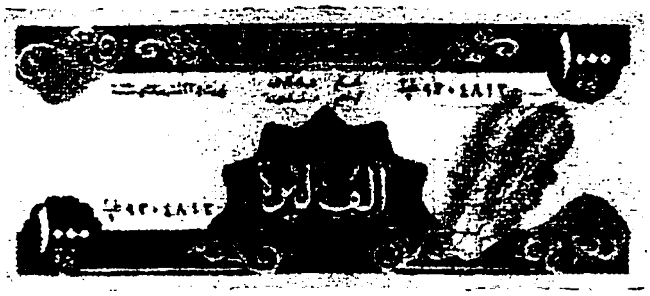
Analysis of Variance Tables for Oral Version of Dehaene and Akhavein's Bimanual Study

Main Effect	
Left-Right/Right-Left	$F(1,19) = .514$, n.s.
Notation	$F(3,57) = 31.98$, $p < .001$
Interaction Effect	
Left-Right/Right-Left x Notation	$F(3,57) = 6.32$, $p < .001$

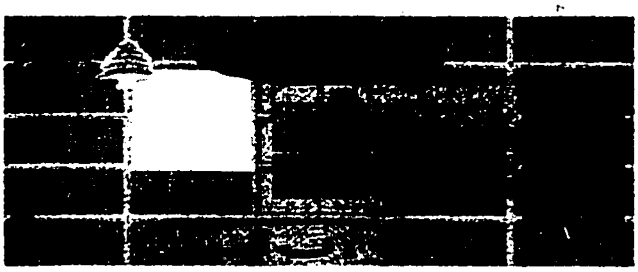
Appendix F

Standard Bills from Bill and Numeral Study

1,000 lira

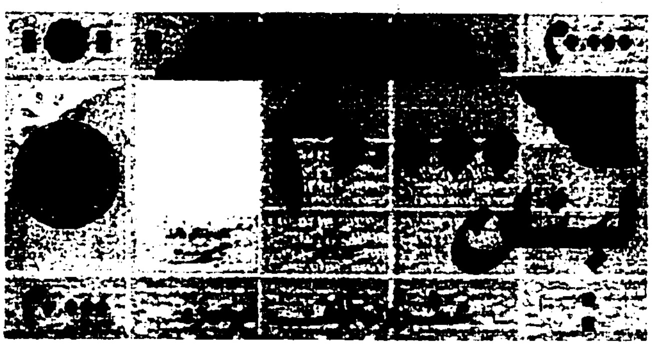


5,000 lira



10,000 lira

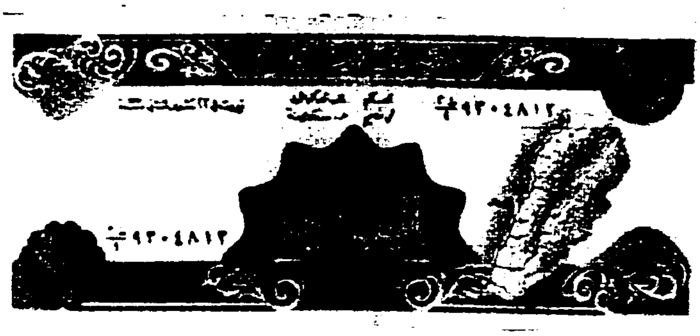
20,000 lira



50,000 lira

Numeral Occluded Bills from Bill and Numeral Study

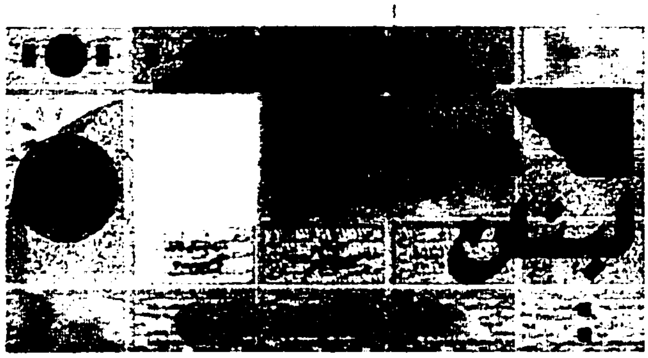
1,000 lira



5,000 lira

10,000 lira

20,000 lira



50,000 lira

Currency Numeral Only Bills from Bill and Numeral Study

1,000

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5,000

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10,000

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20,000

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50,000

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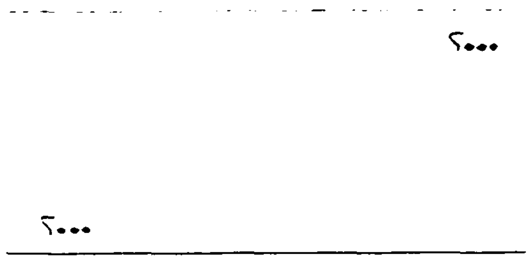
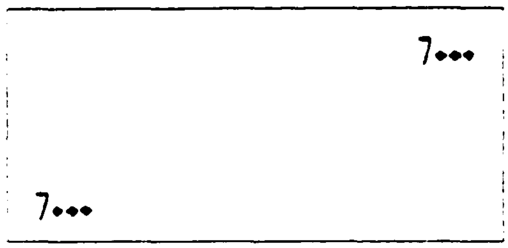
Appendix I

Non-Currency Numeral Only Bills from Bill and Numeral Study

2,000



6,000



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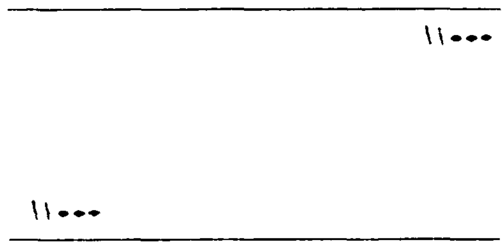
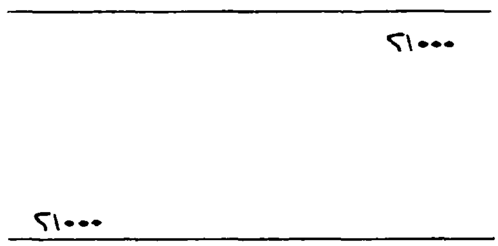
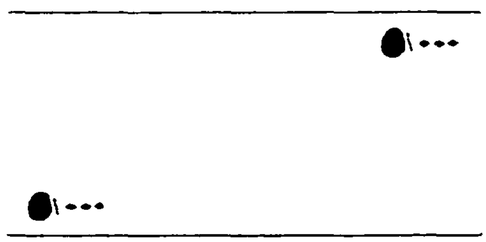


21,000



51,000



Appendix J

Table of Error Types from Bill and Numeral Study

	Bills	Naming Errors	Non-Trials	Outliers
Traditional Non-Sellers	Standard	0		
	Numeral Occluded	7		
	Currency Numeral Only	10		
	Non-Currency Numeral Only	14		
		31	159	14
Traditional Sellers	Standard	2		
	Numeral Occluded	7		
	Currency Numeral Only	12		
	Non-Currency Numeral Only	7		
		28	148	21
Modernising Non- Sellers	Standard	1		
	Numeral Occluded	4		
	Currency Numeral Only	1		
	Non-Currency Numeral Only	6		
		12	195	15
Modernising Sellers	Standard	1		
	Numeral Occluded	3		
	Currency Numeral Only	6		
	Non-Currency Numeral Only	2		
		12	93	16

Appendix K

Analysis of Variance Tables for Bill and Numeral Recognition Study

Main Effects	
Selling Practice	F (1,35)= 33.188, p < .001
Level of Modernisation	F (1,35)= 13.51, p < .001
All Bills (repeated measure)	F (1,35)= 99.025, p < .001
Interaction Effects	
All Bills x Selling Practice	F (1,35)=5.82, p < .001
All Bills X Level of Modernisation	F (1,35)= 6.09, p < .001
Selling x Modernisation	F (1,35)= 1.220, n.s.
All Bills x Selling Practice x Level of Modernisation	F (1,35)= 5.59, p < .05

Appendix L

Analysis of Variance Results for Large Number Concept Priming Study

Main Effects

Numeral Occluded Type vs Numeral Only Type	$F(1,35)= 14.177$, $p < .001$
Related-Unrelated	$F(1,35)= 6.717$, $p < .001$
Selling Practice	$F(1,35)= 27.20$, $p < .001$
Modernisation	$F(1,35)= 6.717$, $p = .011$

2-way Interactions

Occluded-Numeral Prime Type x selling	$F(1,35)= .342$, n.s.
Occluded-Numeral Prime Type x Modernisation	$F(1,35)= 1.30$, n.s
Related-Unrelated x selling	$F(1,35)= 1.57$, n.s.
Related-Unrelated x modernisation	$F(1,35)= 1.30$, n.s
Related-Unrelated x Occluded-Numeral Prime	$F(1,35)= 16.137$, $p < .001$
Selling Practice x Modernisation	$F(1,35)= .028$, n.s.

3-way Interactions

Occluded-Numeral Prime type x selling x modernisation	$F(1,35)= .086$, n.s.
Related-Unrelatate x selling x modernisation	$F(1,35)= .292$, n.s.
Related-Unrelated x Occluded-Numeral Only Prime Type x selling practice	$F(1,35)= .409$, n.s.
Related-Unrelated x Occluded-Numeral Only Prime Type x modernisation	$F(1,35)= 4.4$, $p < .05$

4-way Interaction

Related-Unrelated x Occluded-Numeral Only Prime Type x selling practice x modernisation	$F(1,35)= 2.2$, $p = .14$, n.s.

Appendix L

Ethics Approval

The University of Western Ontario
Department of Psychology

May 31, 1999

M E M O R A N D U M

To: Samar Zebian
From: Jim Olson on behalf of the Ethics and Subject Pool Committee
Re: Ethical review of "Numerical processing and perceptual...."
Protocol # 99 05 05

STATUS

_x_ Approved
___ Approved conditional to making changes listed below (please file changes with your application to use the subject pool with Helen Harris in Rm. 7304)
___ Please make the changes listed below and resubmit for review

SIGN-UP POSTER

___ Briefly describe the task required of subjects
___ Do not "hype" the advertising of your study
___ Use 10cpi or 12cpi, with standard letter size, for description
___ Other (see attached sheet)

INFORMED CONSENT SHEET

___ Briefly describe the task the subjects are agreeing to perform
___ Promise that the data will be kept confidential and used for research purposes only
___ Promise that audio and/or video tapes will be erased, in part or entirely, at the subjects' wishes at any time
___ State how many credits the subjects will receive for participation
___ State that subjects may terminate the experiment at any time without loss of promised credit(s)
___ State that there are no known risks to participation or state the risks
___ State that subjects will receive written feedback at the end of the session or study and/or that subjects have had an opportunity to ask questions about the study
___ Other (see attached sheet)

WRITTEN FEEDBACK

___ Elaborate your feedback
___ Rewrite your feedback at a level that is understandable to a Psychology 020/023 student
___ Add a few references at the end and/or your name and how you can be reached
___ Other (see attached sheet)

OTHER ___ See attached comments

c. P. Denny

Samar — Please make the 3 minor corrections indicated on the consent form for Subject Pool par

Vita

Name:	Samar Zebian
Place of Birth:	Zahle, Bekka Valley, Lebanon
Year of Birth:	1970
Post-Secondary Education:	The University of Western Ontario London, Ontario, Canada 1989-1993 B.A. (Honours-Psychology and Philosophy)
	The University of Western Ontario London, Ontario, Canada 1994-1996 M.A. (Cognitive Psychology)
	The University of Western Ontario London, Ontario, Canada 1996-2000 Ph. D. (Cognitive Psychology)
Honours and Awards:	Special University Scholarship 1994-2000.
Related Work Experience:	Teaching Assistant

Pulbications:

Zebian, S. & Denny, J. P. (in press). Integrative cognitive style in Middle-Eastern and Western groups: Multidmensional classification and major and minor property sorting. Journal of Cross-Cultural Psychology.