BRILL

Journal of Cognition and Culture 8 (2008) 359–385

www.brill.nl/jocc

Number Conceptualisation among Lebanese Micro-Business Owners who Engage in Orally-Based *Versus* Paper-Based Numeracy Practices: An Experimental Cognitive Ethnography

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Abstract

The study of everyday numeric thinking in adults directs our attention to several aspects of number cognition that have received almost no attention in the experimental cognitive science literature, namely the influences of socially situated artifact use on numeric processing. The current studies explore numeral recognition and conceptualisation processes in business people who engage in different types of numeracy practices; orally based numeracy practices which involve very little use of written records compared to paper-based numeracy practices. Ethnographic observations of Lebanese business people were conducted to gain a detailed understanding of the socio-cognitive demands in orally-based paperless and paper-based business settings. These observations were in turn used to design experimental reaction time studies which investigated currency based numeral recognition and conceptualisation processes. The results of the numeral recognition and priming studies clearly illustrate that the use of artifacts in everyday numeracy practices influences numeral recognition and conceptualisation in a way that suggests tight linkages between the visio-spatial processes involve in recognizing numerals embedded in cultural artifacts and the semantically based processes involved in the conception of these numerals. The relevance of the current findings for the main models of adult numeric cognition and for research on everyday numeracy will be discussed.

Keywords

Numeracy, number conceptualisation, cognitive ethnography, literacy

In this study I attempt to integrate two perspectives, a cognitive scientific and a cultural constructivst approach, to numeric cognition to examine whether specific kinds of numeric thinking develop in individuals who engage in different kinds of routinised and pervasive artifact mediated numeracy (number literacy) practices, namely orally-based and paper-based business numeracy. A

DOI: 10.1163/156853708X358227

detailed account of orally-based and paper-based practices will be reported later in study 1; however, it will suffice at this time to define orally-based numeracy practices as those involving a great deal of mental numeracy and a strong de-emphasise on written numeracy practices. For example, orally-based numeracy practices rarely involve creating written records of sales and purchases. Paper-based numeracy practices involve creating and using written records. For example, daily sales are logged, employee working hours are recorded and bank statements are monitored. Two main studies explore the numeric cognition processes in individuals who engage in orally-based and paper-based numeracy. The first study is a cognitive ethnography which examines the socio-cognitive skills involved in each practice. Based on the cognitive ethnography an experimental reaction-time study was designed to assess whether the socio-cognitive skills observed in everyday contexts give rise to specific forms of on-line numeral recognition and conceptualisation processes. The main question in these studies is whether orally based numeracy practices affect the way currency based magnitudes are recognised and conceptualised and whether some aspects of the viso-spatial properties of the currency become an integral part of numeric recognition and conceptualisation.

The focus on everyday work related numeracy practices raises new issues with respect to number conceptualisation which are almost completely not acknowledge in the adult numeric cognition literature. Cultural psychologists, interested in everyday cognition have stressed how the development and employment of mathematical and numeric knowledge is deeply shaped by higher order cognition, and the use of material and symbolic artifacts and fundamentally shaped by socially situated goal-directed practice. A heuristic example of this work is from the arithmetical practices of unschooled Brazilian child street sellers who compute their retail prices not by percentage-profit algorithms but by a quantification practice which involved emptying the contents of a box (containing 30, 50 or 100 chocolate bars for example) and then returning the units in groups of 2, 3 or 4, that corresponded to several price ratios, i.e., 2 for 500 cruzeiros, or 3 for 1000 cruzeiros (Saxe, 1991). If the total turned out to be an undesirable value the seller would re-empty the box and recount using a lower or higher counting unit until he got the appropriate profit margin. A wide range of artifact mediated and other cultural forms are used in this quantification practice (Saxe, 2004). For example, when sellers return the candy to the boxes they are using currency units to perform various arithmetical operations (i.e. one thousand cruzeiros). Additionally, the box is a convenient repository that simultaneously represents the wholesale and retail price of the product. According to social constructivists, socially situated and artifact mediated cultural forms fundamentally shape mathematical thought

and establish the conceptual starting points for later quantitative thinking (see also Lave, 1977; 1988; Saxe, 1982,1985, 1991; Hatano and Osawa, 1983; Scribner, 1983; Denny, 1986; ; Hatano et al., 1987; Ascher, 1991; Lakoff and Miller and Stigler, 1991; Millroy, 1991; Nunes et al., 1993; Nunez, 2000; Saxe and Esmonde, 2004, in press; Choa et al., 2000). Despite the important contributions of these diverse researchers, they have not actively developed processing accounts and empirical methods to investigate whether socially situated artifact use and higher order cognition have direct consequences for the way numbers are cognitively represented and processed, although many advocate this type of research (Scribner, 1982; Lave, 1988, Millroy,1991; Hutchins, 1995b).

In comparison to social constructivist approaches, the cognitive science work on adult numeric cognition is mainly concerned with understanding whether the semantic representation of Arabic numerals is a notation independent code or whether there are multiple semantic codes which are notation dependent. Although, this body of work does not investigate the influences of other "notational" systems, such as those embodied in currency and other artifacts, the models are useful in that they offer the only known on-line processing accounts of how notational processes affect number conceptualisation. This is important in the current study because we question whether the viso-spatial properties of currency based numerals, such as the pattern and colour of the bill, influence how currency based magnitudes are internally represented. There are three main models in the adult numeric cognition literature that take up these issues with respect to written and spoken Arabic numeral forms and their views fall along a continuum from notation-independent to notation-specific hypotheses (Campbell and Clark, 1988; McCloskey, 1992; Dehaene, 1992; Campbell, 1994).

At the notation-independent end of the continuum, McCloskey's view is that the core of a number concept, or the semantic representation, is one common magnitude code that is independent of number notation and modality (McCloskey, 1992; McCloskey et al., 1986, 1992). According to this view, numeric inputs (written or spoken number words) are obligatorily translated by an anumeric notation specific module that does not effect or modify magnitude-based processing. As such the magnitude code is insulated from other cognitive processes to the degree that the code even functions independently of the numeric decoding and production systems (McCloskey, 1992; McCloskey et al., 1986, 1992). In relation to the questions posed in the current study, the amodal view would predict that the viso-spatial processes involved in recognizing currency based numerals are completely separate from the processes involved in conceptualising currency based magnitudes. Dehaene's triple code model also posits the modularity of the semantic representations of numerals

and offers empirical and neurologically supported findings which suggest that the semantic code is independent of number notation and modality.

At the other end of the continuum, the notation-specific end, Clark and Campbell's encoding-complex view proposes that numeric processes are grounded in modality-specific codes (visuospatial and verbal-auditory codes) that are interconnected to a complex and highly integrated magnitude based associative structure (Clark and Campbell, 1988, Campbell, 1994; however, see McCloskey, 1992 for an alternative interpretation). These interconnections between the magnitude code and particular notations arise out of idiosyncratic learning histories, and could be shaped by socially situated practices, but nothing more is said about how these influences and contexts modify the magnitude code, nor the implications for architectural models of numeric cognition. Applying this model to bill and numeral recognition, it would hold that differences in numeral recognition reflect qualitative differences in number conceptualisation because the surface features of number codes are tightly associated with its magnitude and semantic features.

At first sight it may seem that the cognitive and the social constructivist approaches to numeric thinking are incommensurable especially because none of the three models offer a functional account of numeral systems embedded in physical artifacts and because they are only concerned with literacy based numeric cognition. Save for a passing acknowledgement by Campbell (1992) 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), 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, nor does this body of research offer empirical evidence to extend their claims to artifact mediate numeric cognition. However, I think it is possible and useful to strategically coordinate them because the cognitive approach offers a way of thinking about how surface notation is recognise and decoded and how these processes are related to semantically-based processes, while the constructivist perspective is acutely sensitive to the socially situated cognitive demands of numeric practices. Put them together and you have an ecologically informed approach to numeric cognition.

Saxe's Ethnographic Studies of Work-Related Numeracy Practices

Saxe's (1991) research on business numeracy among Brazilian child street sellers is one example of a cognitively informed ethnography of numeracy. This

study will be reviewed in detail because it is similar in many ways with the current study and because there is such little cognitively-oriented and ethographically rich work on adult everyday numeracy practices (for a few exceptions see Scribner,1985; Millroy, 1991; Saxe and Esmond, in press). In the observational phase of the study, Saxe watched child candy sellers (with varying levels of schooling) read numerals, handle printed material, and engage in other numeracy practices. Several sources of converging observations suggest that they do not rely on printed prices in their quantitative practices. Before making the purchase, forty one percent of the sellers reported that they already knew the prices from other sellers or from previous experience and the majority did not ask the wholesale clerk for the prices. Also, wholesalers reported that 45% of the sellers asked about the number of units in the box and either did not read the box, or sought an oral confirmation of what they read or were previously told by other sellers. Together these observations and others reported by Saxe suggest that numeral reading and paper-based numeracy practices are not obligatory in this context.

The candy sellers' purchasing strategies might seem surprisingly inefficient compared to numeral reading and other literate numeracy practices, especially considering that the sellers all had functional literacy skills, however, Saxe shows us that they are viable because of various historical factors. Wholesale prices fluctuated frequently due to inflation and even when prices are listed they do not reflect the current value of a product but merely a base price from which to start bargaining. As such the printed price of a product provided little useful information and may have been secondary to the seller's networking skills. Based on the pervasive features of these numeracy practices, Saxe developed the Bill and Numeral Identification task to assess whether child sellers had developed currency based representations (Saxe, 1991; see also Heath, 1983; Street, 1984; Wagner, 1993 for descriptions of highly contextualized literacy practices). The task was administered in a controlled setting to street sellers and schooled children. The participants were required to name three types of currency bills. In 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. Using only an off-line measure, correctly naming the bills, results showed that schooled non-sellers performed significantly better than the sellers when naming stand alone numerals, i.e., the Numeral Only condition. The sellers did not accurately identify numerals without the bill context. Standard Bills and Numeral Occluded Bills were named equally well

by both the sellers and the schooled non-sellers 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. These findings suggest that socially situated artifact use influences numeric processing, however, a finer grain of analysis, afforded by experimental cognitive methods, is needed because pattern and number recognition is very quick and cannot be adequately assessed by off-line methods. Moreover, a theoretically and empirically related issue is whether these numeral recognition processes are related to deeper aspect of number conceptualisation and magnitude processing. Finally, we are also interested in examining whether these orally based numeracy skills are observed in adults, or whether they have more abstracted "artifact-independent" numeric cognition.

Study 1: Cognitive Ethnography of Orally-Based and Paper-Based Business Numeracy Practices

To enable fine grained exploration of the potential influences that artifacts have on numeric cognition, it is necessary to begin with a detailed and systematic account of how artifacts are used in everyday numeracy practices. Artifacts have structural, computational properties, and properties that extend cognition and create larger thoughts system that the brain coordinates. To understand these larger thought systems we need a detailed understanding of how artifacts are used in daily practice (Scribner, 1983, 1986; Lave, 1988; Hutchins, 1995a, in press; Saxe and Esmond, in press;). The failure to see cognitive artifacts in their broader social context will likely tell us very little about their influences on quick cognitive processing. As such an ethnographic study of everyday numeracy practices in a variety of Lebanese micro-businesses was conducted.

I visited and observed several family-run and sole proprietor micro businesses in the Southern and Bekka regions of Lebanon. In these businesses, all of which were run by literate business people, I observed a number of tightly interrelated practices which I refer to as "orally-based" business numeracy and "paper-based" numeracy. The businesses observed were similar in many ways and functioned in very similar socio-economic contexts: (1) all were sole-proprietor micro businesses that were located in villages or small city centers, (2) employed 1–5 employees, many of whom had some kin relation to the owner, (3) their customer base included working class patrons, (4) no printed advertising promotions were used, (5) businesses were either neighborhood food stores or small clothing outlets, (6) product prices were not marked since the common practice was to bargain for the final price or to ask for the price.

However, the shops differed in one important way. The village micro businesses had a smaller and a less diverse customer base whereas the customer base in the city typically extended beyond the extended family and neighborhood customers. Beyond this difference, there were no clear socio-economic variables that differentiated the businesses observed.

Orally-Based Paperless Business Numeracy Practices

Printed material plays a limited role in orally-based paperless business practices (Figure 1). It is not completely absent, however, it is used in limited situations, and in ways that differ from those who practice paper-based literacy. In the orally based businesses, paper was used infrequently, and this was not a result of its availability since most of these shops sold loose paper and writing pads. It was rare to see notes, reminders, letters, and sales journals. Even when writing was used, the written record was not saved nor pinned up for future reference. Instead, written records were temporary memory aids that were quickly discarded. Written letters and notices were rarely used as substitutes for face to face interaction, nor for passing on messages to customers or other employees.

Sales receipts and other printed materials were not used in sales transactions. In orally-based businesses, cash registers were either unavailable or were used only to secure cash or personal belongings. No clerk was observed issuing sales receipts in the 4 month period of observations. This is not an unusual

Figure 1. An orally-based seller at work in a small retail clothing shop

situation, since sales receipts are not an enforced requirement in Lebanon due to longstanding political instability which has made it impossible for the government to collect retail taxes in most regions of the country. Receipts were not even used when customers bought on credit, which they did frequently. For these transactions, the clerk ritualistically added up the purchases out loud, the customer verbally acknowledged the amount owed and after the customer left the shop, the clerk would enter the amount owed in a log book as it was considered impolite to do this in front of the customer. The details of the transaction were not recorded (i.e., itemized purchase list or date) since the store clerk personally knew each customer, usually through kinship. The logs served only as a personal reminder to request payment or limit purchases. A further indication that the records kept were not veridical free-standing documents was that 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, the customer's kinship network, and the effect that such as dispute would have on the broad and very complex forms of reciprocal exchange. Further evidence that written numeracy practices are de-emphasised was revealed in the extensive emphasis on detailed memories for wholesale costs, retail prices, and economic transactions with customers and distributors. The prices of items were rarely marked on the products nor were price lists used. Store owners and clerks often laughed when I asked them how they could remember everything. Their memory for work related details was a source of pride for them and they felt that relying on printed text was not only cumbersome, but reflected slow "wittedness".[1]

Emphasis on orally-based numeracy practices was also observed in the way clerks and store owners purchased merchandise from distributors. The prices of the purchased products were often summed orally and no receipts were issued or requested even in situations where shopkeepers paid monthly invoices. In such cases, the distributor independently recorded the invoice total and sometimes the details of the purchase. Some shopkeepers kept their own records, while most did not. Those that did not keep written records made use of rich memory strategies to consolidate episodic memories of the transaction. They were observed counting aloud as the distributor counted the merchandise. The actual social exchange between the shopkeeper and the distributor often was quite lengthy and involved ritualistically repeating counts and totals more than once. Other forms of interaction and exchange were observed which turned this mundane and routine activity into a culturally rich exchange that helped consolidate episodic memories of economic transactions.

[1] a direct translation of the Arabic term.

The ethnographic observations suggest that orally-based numeracy practices do not obligatorily require sellers to think about numerals and quantities in a decontextualised way. The numeral is rarely thought about, written down, or handled outside the context of currency and therefore it is hypothesized that orally-based sellers might recognise the value of a currency bill faster than they recognise the same value presented as a stand alone number, i.e. without the bill context. A different hypothesis is posited for the paper-based sellers, however the ethnographic findings will be presented first.

Paper-Based Business Practices

Observations of the daily business practices in other businesses showed a much more pronounced emphasis on paper-based numeracy practices. In these businesses, clerks made use of cash registers or receipt books to record retail transactions. Daily and monthly sales receipts and records were used for accounting purposes and to monitor cash flow and product sales.

In addition to these written records, clerks and owners of these shops kept written logs of all customer credit. It was necessary for these logs to be very precise and accurate since they had a much larger customer base, many of whom were infrequent customers. Some but not all sellers gave the customer a receipt for products taken on credit. For familiar customers this exchange was largely seen as unnecessary and slightly embarrassing, however a record of the credit was still entered after the customer left which suggests that the written record was a necessary memory aid. Other observations suggested that it had more of a primary role in mediating later exchanges. I observed sellers refer to the written record when collecting overdue payments suggesting that the written record was invested with a kind of veridicality that was not present in orally based practices. Paper-based store owners and sellers complained bitterly about managing customer credit; however, this is an unavoidable practice in Lebanon since credit cards and cheques are not widely accepted and since the working class customer base of these businesses had been significantly affected by Lebanon's unstable economy.

In paper-based numeracy, monetary values and economic transactions are re-represented in sales ledgers, payment invoices, lists, receipts, and the like, and outside the immediate context of currency, and social transactions. The Paper-based sellers should not be significantly slowed down by the absence of the bill context and should be able to read stand alone currency based numerals without additional processing cost. It was also hypothesized that these recognition skills will be related to numeral conceptualisation skills. The hypotheses from the ethnographic study were tested in two reaction time studies.

Study 2a: Bill and Numeral Naming Task Method

Participants

Thirty-nine individuals from four identifiable groups of orally-based and paper-based sellers and non-sellers participated in the current studies. Participants were assigned to one of the four groups (which will be described below) after observing their numeracy practices. This process was time consuming and involved applying strict criteria for group assignment. As such the number of participants in each group was relatively low; nevertheless, the low number of participants decreases the statistical power of the analyses and subsequently provides a very conservative estimate of the hypothesized group differences.

Orally-based sellers. The 10 sellers in this group were observed engaging in Orally-based business numeracy. They were either owner/operators or family members working as clerks, or paid apprentices in five different micro-businesses. The ten participants in this group were from 3 small village businesses and two urban based businesses in Lebanon. They were nine men and one woman, ranging in age from 19 to 39 years. The Orally-based Sellers had up to, but not beyond, high-school education in state-run Lebanese or Syrian schools. All of these participants were literate.

Paper-based sellers. The 9 male sellers in this group were owners or clerks in micro-businesses, ranging in age from 22 to 39. The businesses were located in two villages and two small cities in the Southern and Bekka regions of Lebanon. Unlike the Orally-based sellers, paper-based sellers were observed spending 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 the orally-based owners who were observed spending most of their time socialising with their customers as a means to maintain their customer base. All the Paper-Based Sellers had at least high-school levels of education. Four of the nine sellers had finished Bachelors degrees in Lebanese state-run universities. Paper-Based Sellers, compared to Orally-Based Sellers, had higher levels of education. Consequently, there is an unavoidable correlation between the type of numeracy practice and level of education. For the current study no attempt was made to separate the largely inseparable influences of educational background and type of numeracy practice.

Orally-Based Non-Seller Group. In addition to the two sellers groups, two comparable non-seller groups were administered the Bill and Numeral Task.

There were 7 female and 3 male Orally-based non-sellers ranging in age from 17 to 45. Non-sellers were also observed to engage in more orally-based numeracy practices and to strongly deemphasize written numeracy. Orally based non-sellers were individuals who were either not employed or employed in a non-retail job. They had up to but not beyond grade-school education which was comparable to the Oral seller group.

Paper-Based Non-Seller Group. In the Paper-based Non-Seller group there were 5 females and 5 males, ranging in age from 19 to 44. Four of these non-sellers had completed an undergraduate university degree, and three completed teachers' college training. They worked as teachers or telephone operators, and three of them were university students in the Lebanese State University. They were observed to engage in paper-based numeracy practices.

Apparatus

A MacIntosh Powerbook laptop with a 14" Colour Liquid Crystal Display Monitor was used to present the stimuli. A MacIntosh Simple Talk external microphone was connected directly into the microphone plug in the computer. The software program Superlab (Cedrus, version 1.74) detected voice onset and recorded the length of time that passed between the visual stimulus onset and the onset of the voiced response to 1 ms accuracy. Superlab was also used to display the stimuli and collect RTs. There is an unavoidable source of error variance when measuring RT using laptop computers with LCD screens which arises from an approx. 15 ms asynchrony between the refresh rates of the screen and the processing cycle of the CPU. This structural constraint is an unavoidable source of error variance in this study.

Materials and Scoring

Bill and Numeral Recognition Stimuli. Participants were required to name the value of four stimulus types: Standard Bill (the face of different standard Lebanese currency bills), Numeral Occluded (standard bills with their numerals occluded), Currency Numeral Only (stand alone currency numerals displayed without the visuo-spatial properties of the bill), Non-Currency Numeral Only Bill which contains values that do not appear on currency bills (i.e., 2000, see Appendix A). The Non-Currency Numeral Only stimuli was used only as a filler to create variability in the presented values. For each stimulus type, five currency values were randomly selected to create each stimulus type: 1000 LL (Lebanese pound), 5000 LL, 10 000 LL, 20 000 LL and 50 000 LL. Each stimulus type was presented 64 times for a total 256 randomly presented trials.

Half the trials were presented in the first block followed by a short break, and then the second-half of the trials were presented.

Bill and Numeral Priming Study. Half of the 256 trials described above (128 trials) were used to create paired trials for a priming study to asses whether Standard Bills could be primed by two types of bills, Numeral Occluded and Currency Numeral Only. For the priming study, each target Standard bill was immediately preceded by a related or unrelated prime Currency Numeral Only prime or a related or unrelated Numeral Occluded prime. Taking Numeral Occluded priming as an example, 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 the 16 unrelated prime-target pairs, each of the four Standard Bills was paired with four unrelated Numeral Occluded Bill primes that did not have the same numerical value. The same number and proportions of trials was used for the Currency Numeral Only priming type. In total, 64 stimuli where used to assess each type of priming. The dependent variable in the priming study was the difference in the length of time it took to name a primed versus an unrelated Standard Bill.

Procedure

The participants were new to psychological experimentation and as such time was allotted to introduce them to the laptop since some had never seen a computer and many had never used one. Also, time was spent training them to do the task quickly and to coordinate their responses with the stimulus presentations. Care was taken not to over-tax them since the task required them to sustain their attention in a novel way. During training phase, four participants were excluded from the study because they had trouble reading the stimuli and found the novelty of the task uncomfortable.

For the test phase of the study, participants were instructed to quickly and accurately name the stimuli presented on the screen. The stimulus was displayed on the screen until there was a verbal response. The response was followed by a 600ms ISI. Participants named 128 trials in the first block, received a break and then named the remaining 128 trials. Generally, I found participants attentive and willing to respond to each trial quickly since many believed that I was assessing their speed of wit or intelligence. Although this construal is incorrect, it facilitated the type of consistent speeded behavior that is required for the RT studies. There was however, some outside interruptions which gave rise to a higher level of outliers than is common in RT studies with university participants tested in quiet lab settings. An analysis of the outliers for each stimulus type revealed a completely random pattern across the stimulus types.

Results and Discussion

Study 2a: Bill and Numeral Recognition

In the Bill and Numeral Recognition Study (Study 2a) a 2×2×4 mixed analysis of variance assessed how selling practice (sellers compared to non-sellers) and numeracy practices (orally-based compared to paper-based) affected recognition speed for: Standard Bills, Numeral Occluded, Currency Numeral Only Bills, and Non-Currency Numeral Only Bills. A summary of the full analysis of variance results for this study appears in Appendix B.

Bill and Numeral Recognition and Within-Subjects Main Effects

Collapsing across the main effects, there was an overall significant difference in the length of time it took to name each of the four bills, $F(3,105)= 99.01$, $P<0.001$. As can be seen in Table 1, the Standard Bills were named faster by all groups followed by the Numeral Occluded Bills, followed by the Numeral Only Bill.

Table 1
Bill and Numeral Recognition Study: Naming times in milliseconds for the Standard, Numeral Occluded, Currency Numeral Only Bills, and Non-Currency Numeral Only Bills

Group	Standard bills	Occluded bills	Currency numeral only bills	Non-currency only bills
Orally-based non-sellers (*N*=10)	825 (54)	896 (63)	1033 (106)	1133 (111)
Orally-based sellers (*N*=10)	724 (46)	797 (72)	871 (94)	865 (54)
Mean	774 (71.7)	846 (83)	952 (128)	999 (162)
Paper-based non-sellers (*N*=10)	774 (74)	849 (87)	908 (108)	916 (122)
Paper-based sellers (*N*=9)	670 (67)	739 (77)	803 (79)	807 (91)
Mean	722 (87)	794 (98)	856 (107)	862 (120)
All Lebanese groups combined (*N*=39)	748 (83)	820 (93)	904 (126)	931 (157)
Euro-Canadian university students (*N*=19)	628(104)	783 (133)	665 (86)	669 (101)

Tukey HSD apriori post hoc tests with an alpha level set conservatively at $P<0.01$ revealed that the Standard Bills were named 72 ms faster than the Numeral Occluded Bills, $Q(3,105)=8.65$, $P<0.001$. Numeral Occluded Bills were in turn named 84 ms faster than the Currency Numeral Only Bills, $Q(3,105)=10.04$, $P<0.001$. The remaining pair wise comparisons were not of theoretical significance and will not be discussed.

These findings show that when the RT for all groups is collapsed, the real-world Standard Bill was named faster than the more novel Numeral Occluded Bill. Thus the absence of the numeral significantly slowed down bill recognition when the RT for all groups were collapsed. Moreover, the Currency Numeral Only Bills which consisted of numerals presented without the bill context were named 183 ms slower than Standard Bills, and 84 ms slower than Numeral Occluded Bills. Thus it seems that the absence of a visuospatial bill context dramatically slows down numeral recognition more than the absence of the written numeral. This high level of contextualized numeric recognition processes, where the visuo-spatial context seems to have a significant and unexpected affect orthographic recognition, has been observed to vary considerably across cross-cultures (Cole et al., 1971; Berry, 1976; Scribner, 1977; Heath, 1983; Berry et al., 1986; Denny, 1986, 1991; Chafe and Danielewicz, 1987; Lave, 1996). In light of these findings a small follow-up study was conducted to assess the cross-cultural generalisability of these findings with Canadian university students.

Assessing the Cross-Cultural Generalisability of the Bill and Numeral Recognition Results

The Bill and Numeral Recognition task, with Canadian currency bills, was administered to a group of Euro-Canadian university students. Results of a completely within-subjects analysis of variance revealed an overall significant difference in stimulus naming times, $F(3,27)=30.21$, $P<0.001$. Referring to Table 1 for the mean comparisons, Tukey HSD post hoc tests showed that Standard Bills were named 118 ms faster than Numeral Occluded Bills $Q(3,27)=12.88$, $P<0.05$, which further supports the view that the absence of the numeral significantly slowed down bill recognition in both Lebanese and Canadian groups.

The other posthoc results revealed interesting differences in numeral recognition. First, the Euro-Canadian student group did not name Standard Bills significantly faster than Currency Numeral Only Bills, $Q(3,27)=3.08$, not significant. Standard bills had a small but non-significant advantage of 37 ms, compared to the 156ms advantage for Standard Bills in the Lebanese groups. A second notable finding was that the Euro-Canadians named Numeral Occluded

Bills *slower* by 118 ms than Currency Numeral Only Bills, $Q(3,27) = 9.80$, $P<0.01$. Again this finding directly contrasts with the naming times in the Lebanese groups (collapsing across groups) where Numeral Occluded bills were named 84 ms faster than Numeral Only bills. These findings revealed no processing cost for currency-based numeral recognition in the absence of a visuospatial bill context for the Euro-Canadian group. This was taken as evidence that the linkages between the visuospatial properties of a bill and the written numeral is not as tight for the Euro-Canadian group as it was in the Lebanese groups where there seems to be a tighter connection between the printed currency-based numeral and the visuo-spatial properties of the bill. We will see later that the results from the two Oral groups are primarily driving this cross-cultural difference.

Three-Way Within- and Between-Subject Interactions for the Bill and Numeral Recognition Study

Returning to the main study, three interaction effects were found significant. The length of time it took to name each of the four bills varied significantly with selling practice, $F(3,105)=5.826$, $P=0.001$, and with type of numeracy practice, $F(3,105)=6.01$, $P=0.001$. Moreover, there was a significant three way interaction: naming times for the different types of bills interacted with selling practice and numeracy practice, $F(3,105)=5.59$, $P=0.001$. Subsequently, apriori post hoc tests were conducted on each of the 4 groups separately to answer two questions: (1) are Standard Bills named significantly faster than Numeral Occluded Bills? (2) Is there a difference in the naming time for the Occluded and Currency Numeral Only bills? The Standard Bill RTs were not compared to the Currency Numeral Only Bill RTs because the later were named slower than both the Standard and Occluded bills in all four groups. The alpha level was set conservatively at 0.001.

Orally-Based Paperless Sellers and Non-Sellers

The Orally-based Seller group named Standard Bills significantly faster than Numeral Occluded Bills, $Q(3,105)= 4.45$, $P<0.01$ (Table 1). Numeral Occluded Bills were in turn named faster than Currency Numeral Only Bills, $Q(3,105)= 4.51$, $P<0.01$. These results indicated that the absence of numeral orthography significantly slowed down bill recognition, with the Standard Bills being named 73 ms faster than the Occluded Bills. Additionally, Currency Numeral Only Bills were named 147 ms slower than Standard Bills.

Turning to the Orally Based Non Seller Control group, Standard Bills were named 71 ms significantly faster than Numeral Occluded Bills, $Q(3,105)=$

4.27, $P<0.01$. 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 ms advantage for Occluded bills), $Q(3,105)= 8.37$, $P<0.01$ (Table 1). These result paralleled that observe in the Oral Seller group.

Paper-Based Sellers and Non-Sellers

The Paper-Based Seller group, similar to both Oral groups discussed above, showed faster Standard Bill naming compared to Numeral Occluded Bill naming, $Q(3,105)=4.00$, $P<0.01$ (Table 1). However, unlike the Oral groups, Paper-Based Sellers did not show a significant difference in Numeral Occluded and Currency Numeral Only naming times, $Q(3,105)=3.67$, not significant. These findings reveal that bill and numeral recognition processes in Paper-Based Sellers are not significantly slowed down by the absence of the bill context.

The Paper-based Non-seller Controls, like the three other groups, showed faster Standard Bill naming compared to Numeral Occluded Bill naming, $Q(3,105)= 4.57$, $P<0.01$. Moreover, and similar to the Paper-Based Sellers (but unlike the two Oral groups), Occluded bills were not named significantly faster than Currency Numeral Only Bills, $Q(3,105)= 3.57$, not significant. These patterns of findings parallel those observed in the Paper-Based Seller group.

Discussion Study 2a

The pattern observed in the posthoc findings suggests that specific socially situated numeracy practices, Orally-based compared to Paper-based numeracy practices and not selling practice (taken alone as an independent variable), seems to have some influence on bill and numeral recognition. The parallel findings in the two Oral groups suggest two things. First, with respect to extending Saxe's findings to on-line studies with adults, the absence of numeral orthography did in fact significantly slow down bill identification in adult groups with minimal paper-based numeracy skills. The second finding suggests that the absence of the visuo-spatial properties of a bill dramatically slowed down bill identification, more than the absence of the printed numeral. Together these results strongly suggest that the visuospatial patterns and the printed numeral are a tightly linked percept for individuals who engage in orally-based numeracy. When these interconnections are weakened, slightly weakened in the case of Numeral Occluded naming and strongly weakened in Numeral Only naming, bill identification is slowed down significantly. These findings reveal highly contextualized numeracy processes in adults where the visuo-spatial context is tightly linked to the orthographic properties of the bill (see also Heath, 1983; Street, 1984; Wagner, 1993).

This is an unexpected finding given that some adult numeric cognition research and models assume that number concepts are amodal abstracted representations with no viso-spatial properties (McCloskey, 1992; McCloskey et al., 1986, 1992). In comparison, bill and numeral recognition skills in both the Paper-based groups, where Occluded Bills were named slightly but not significantly faster than the Numeral Only bills, suggests that the recognition of stand alone numerals did not require significantly more processing effort as was the case in the Orally-based groups. For the Euro-Canadian group stand alone numerals were named significantly faster than Occluded bills and as fast as Standard Bills further showing that stand alone numerals do not necessarily require additional processing. The current findings suggest that if there is anything like amodal number concepts, then this type of number concepts develops in individuals who engage in extensive paper-based numeracy practices.

Study 2b

Results and Discussion for the Numeral Occluded and Currency Numeral Only Priming Analysis

In addition to assessing recognition, a sub-set of the data from the Bill and Numeral Recognition task (study 2a) were analyzed as priming data to investigate whether the two types of primes, Numeral Occluded Bills and Currency Numeral Only Bills, facilitated the naming of Standard Bills with the same numerical value. Nonetheless, higher levels of Numeral Occluded priming is expected since the prime (Occluded bill) is visually almost identical to the target (Standard bill). However, Numeral Only priming should happen only if a stand alone numeral invokes the full currency based number concept. 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 primes was compared.

A 2 (related *vs* .unrelated prime)×2 (Numeral Occluded Prime type *vs*. Numeral Only Prime type)×2 (Seller *vs*. Non-Sellers)×2 (Orally-based *vs*. Paper-based) analysis of variance was conducted. The means for this analysis are reported in Table 2. Inspecting Table 2 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 two Orally-based groups and only observed in the Paper-based Seller group. Our 2×2×2×2 analysis of variance yielded several main effects, and several two and three way interactions which will not be reported in the text (see Appendix B), save for the results of one main effect. The related-unrelated main effect was significant; Standard Bill targets (M = 737), that were preceded by a related bill prime (regardless of whether they were preceded by a

Table 2
Large number concept priming study: The mean length of time in ms it takes to name a Standard Bill preceeded by a related and unrelated Numeral Occluded Prime Type and Currency Numeral Only Prime Type

Group		Numeral only priming	Numeral occluded priming
Orally-based non-sellers (*N*=10)	Related primes	848 (67)	800 (92)
	Unrelated primes	824 (71)	819 (55)
	Priming effect	+24**	-19
Orally-based 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
Paper-based non-sellers (*N*=10)	Related primes	774 (81)	750 (100)
	Unrelated primes	784 (68)	789 (75)
	Priming effect	-10	-39*
Paper-based 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 post-hoc tests ($P<0.05$).
** The prime did not facilitate processing speed.

Numeral Occluded or Numeral Only Bill prime) were named significantly faster than unrelated Standard Bill targets, (M = 759), F (1,35)=6.17, P<0.01. This finding is primarily a methodological check for the priming procedure. Finally, 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 Numeracy Practice effect, F(1,35) = 4.482, P<0.05. The means in Table 2 suggest that the differential levels of Numeral Only Priming across the groups may have driven the interaction.

Next, 3 Tukey HSD apriori comparisons will be used to unpack the three-way interaction and build on the findings from the recognition study and will address the following questions: (1) will Orally Based Sellers show the highest level of Numeral-Occluded priming since the recognition results show that the absence of the written numeral on the currency bill does not greatly modify how they conceptualise currency based magnitudes, (2) will Paper-based sellers show the highest level of Numeral Only priming given that the recognition findings show weak connections between the bill concept and the stand alone numeral?

Numeral Occluded Priming Results

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. Looking first at the Orally-based paperless 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<0.05. Numeral Occluded priming was also observed in the Paper-based 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<0.05.

As a follow-up to the numeracy practice effect for the Numeral Occluded priming results, planned Tukey HSD posthoc tests were conducted to assess which group showed Numeral Occluded priming since levels of priming varied considerably. Looking at the priming effect separately within each of the four groups, results showed significant levels of priming in the Oral Seller group, Q(60, 6) = 5.212, P<0.05, and the Paper-Based Seller group, Q(60,6) = 3.10, P<0.05. The size of the priming effect was 70 ms among the Oral Sellers in comparison to a smaller 39 ms effect among Paper-based sellers. Looking at the control groups, the priming effect was significant in the Paper-Based

Non-Seller group, $Q(60,6) = 2.9$, $P<0.05$, but not significant in the Oral Non-Seller group, $Q(60, 6) = 1.36$, not significant, whom had the least specialized experience with handling and managing currency as many were homemakers.

It is significant to note that the highest level of priming was observed in the Oral Seller group, which was 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 recognition, and the conceptualisation of numerals in the Oral Seller group. The Occluded priming results further suggest that the presence or absence of a numeral on a currency bill does not significantly change how the bill is conceptualized for sellers since both the Oral and Paper-Based groups show Numeral Occluded priming.

Numeral Only Priming Results

Turning to Numeral Only priming and looking at the Orally-Based group first (Seller and Non-Seller groups combined), results show that the Standard Bill targets preceded by Related Numeral Only Bills ($M = 798$, SD = 47) were not named significantly faster than Standard Bill targets preceded by Unrelated Numeral Only Bills, ($M = 777$, SD = 47), $Q(60.6) = 1.58$, not significant. In fact, there was a non-significant trend in the opposite direction of priming clearly indicating that the pattern of activation for stand-alone currency-based numerals is different than it is for a currency bill of the same magnitude. Results from the Paper-based 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, ($M = 719$, SD = 49) were not named significantly faster than Standard Bill targets primed by Unrelated Numeral Only primes, (M = 739, SD = 49), Q (60.6) = 1.48, not significant. Although a Numeral Only priming effect was not observed in the Paper-Based groups when means were collapsed across the seller and non-seller groups, an inspection of the size of the priming effects for each group in Table 2 indicates that only the Paper-based 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 Paper-based Seller and Non-Seller control groups showed Numeral Only priming. For the Paper-based Seller group, Standard Bill targets primed by related Numeral Only Bills ($M = 664$, SD = 66) were named significantly faster than Standard Bill targets primed by Unrelated Numeral Only Bills, ($M = 695$, $SD = 80$), $Q(60.6) = 2.87$, $P=0.05$. The Paper-Based Non-Seller control group did not show a significant priming effect, $Q(60.6) = 1.37$, not significant.

These patterns of results reveal that written monetary-based numerals share properties with the currency bill concepts such that they cause overlapping

activation and priming in Paper-based Sellers whose numeracy practices involve thinking about monetary values outside the immediate context of currency- in a sense, the numeral is invoking the whole bill concept. This finding fits with the findings of the recognition study which revealed that the written numeral plays an important role in bill recognition among the Paper-based sellers and that its absence significantly slows down recognition.

All together these findings suggest that Orally-based sellers have highly contextualised numeral recognition processes such that the numeral, outside its bill context, does not have independent and autonomous influences on recognition and conceptualisation of currency based magnitudes. The ethnographic observations suggest that the associations between the numeral and the visio-spatial properties of the currency are not strong because Orally-Based Paper-Less sellers do not engage in complex numeric thinking with numerals outside the context of currency mediated social interaction. In comparison, Paper-based sellers do complex reasoning with printed currency based numerals outside the context of currency based exchanges. As such the currency based numeral, independent of the visuo-spatial properties of the currency bill and independent of specific face to face transactions, is associated with the whole bill concept for Paper-based sellers because their numeracy practices involve shifting between written numeracy and orally based numeracy possibly resulting in bi-directional influences between the numeral and the whole bill concepts. These numeracy practices are not observed in any other group, namely they are not observed in the Paper-Based Non-Seller group who show similar patterns of recognition but not similar conceptualisation processes. This last finding clearly shows that socially situated and artifact mediated cognition has different influences on thought depending on the way in which individuals use numeracy in everyday practice.

4-way Interaction

The Numeral Occluded-Numeral Only Prime type×Related-Unrelated×numeracy practice×selling practice interactions approached but did not reach significance, $F(1,35) = 2.27$, $P = 0.14$, suggesting that selling practice does not significantly account for additional variability in the priming results. These results are understandable since only the Paper-based Non-Seller group, but not the Oral Non-Seller group, showed Numeral Only priming.

Overall Discussion

The findings from the recognition and priming studies contribute to our understanding of how artifact use in different numeracy practices shape numeral

recognition and conceptualisation. The results of the recognition study support and extend Saxe's findings which show the off-line influences of orally-based numeracy practices on children's numeric thinking. The current studies confirm the depth and specificity of these influences since orally based numeracy practices affect the on-line recognition and conceptualisation processes of adults who are assumed to have sophisticated numeric skills that are no longer representation specific and are no longer grounded in specific symbolic and physical structures (for similar conclusions in other socio-cognitive domains see also Scribner and Cole, 1981; Lave, 1977). The current findings seem to question claims made by some scholars that artifacts only affect the early number concepts of novices and the further assumption that these influences diminish as adults loose representation-specific and artifact-related representations (Hatano, Amaiwa, and Shimizu, 1987; Hatta, Hirose, Ikeda, and Fukuhara, 1989; Hishitani, 1990; Miller and Paredes, 1996; Stigler, 1984). Although the current findings do not rule out the possibility that artifact specific representational processes will change or develop with expertise or age, I am suggesting that this isn't a foregone conclusion and that it is difficult to predict developmental changes without detailed knowledge of the pervasive aspects of socially situated artifact use over time. A significant step in understanding how artifacts affect thought involves understanding what dimensions of socially situated artifact use will impact which kinds cognitive processes. Artifacts do not merely amplify thoughts but rather call upon cognitive processes which enable the coordination of different representations in a way which achieves or approximates socially situated task goals (see also Hutchins, 1995a, chapter 3 for a fuller discussion of the influences of physical artifacts on quantitative thinking). In the numeric cognition field, there is no known work which uses these multiple units of analysis (observations of everyday behavior and on-line studies) as a means to think about everyday numeracy practices that have different ontological origins.

Implications of the Current Findings for Models of Adult Number Processing

At this point it is useful to step back and consider the potential implications of the current findings for models of adult numeric cognition which take up the general issue of how numeral recognition and decoding processes are associated with semantically based processes. First, the current findings suggest that numeral recognition skills reflect deeper characteristics of number conceptualisation, a view expressed in the encoding complex model which acknowledges and explores the linkages between semantically-based magnitude processes, and decoding processes, while also admitting the influences of learning history and artifact use on magnitude processing. Turning to the triple code model, it might predict that the linkages between the notational processes of currency

recognition and currency based magnitude processes might develop as a result of an individual's learning history and preferred pathways, however it is hard to be sure of Dehaene's views since the model accounts only for the written numeral format and the oral formats of written representations. Furthermore, it is difficult to extend Dehaene's view since he argues that these preferred pathways are not modified by non-magnitude non-quantitative processes, and he explicitly argues that they do not arise from social influences or artifact use. Finally if we turn to McCloskey's abstract amodal model which posits that the number comprehension system converts the surface form of numbers (notational properties) into a common abstract code, which then provides the basis for magnitude and semantic-based processing, some questions arise in light of the current findings. For example, why do we observe group differences in the naming of currency magnitudes depending on the surface format, i.e. standard bill, numeral occluded bill and Currency Numeral Only Bill. These differences in recognition time are not a function of the complexity of the visual decoding process since sellers who engage in orally-based numeracy name the more complex format (Standard Currrency bill) much faster than the visually simpler format (Currency Numeral Only Bill). Moreover, if numerals are amodal notation independent representations for all individuals than why do Orally-based Sellers show absolutely no Numeral Only priming while showing large Numeral Occluded priming effects? According to the modularity view, the semantic representation of the currency based numeral should be activated regardless of the notation of the prime. The findings of the current study raise questions about the generalisability of the modularity view, widely accepted in the numeric cognition literature on infants, adults and animals. The current results suggest that for some individuals who do not have strong decontextualised school-based numeracy skills, there may be deep linkages between surface notation and semantic processes. Further investigations are needed to better understand the magnitude codes of individuals who don't engage in traditional numeracy practices. If after further investigations it appears that the semantic core of a number of concepts include notation specific representations for some individuals with similar learning histories we may need to reconsider not only the social and physical ecologies in which numeracy skills develop but the cognitive architecture which supports different ways to represent magnitude.

The Implications of the Current Findings for Cognitive Studies of Everyday Mathematics and Cultural Cognition

Research which attempts the complex task of understanding what aspects of socially situated artifact use shapes and modifies numeric processes benefits from being grounded in ethnographic observations of naturally-occurring

quantitative thinking. This was precisely the early recommendation of Cole (1977) who pioneered cross-cultural cognitive studies of mathematics (Cole, Gay, Glick, and Sharp, 1971). Nevertheless, Cole's early recommendations were not widely taken up by cognitive scientists or cross-cultural math researchers. Instead, this work has been taken up different groups of researchers, namely practice theorists, social constructivists in math education, and some cultural psychologists (see Denny, 1986; Ascher, 1991; Millroy, 1991; Saxe, 1991; Beach, 1995; Hutchins, 1995a; Saxe and Esmond, in press). For various reasons, which are beyond the scope of the current discussion, cross-cultural cognitive psychologists interested in math cognition have not proceeded with the task of coordinating ethnographic and experimental methods. The Bill and Numeral investigations provide one model for cultural maths research where ethnographic observations are used to generate predictions which are then tested experimentally. The experimental results are then interpreted with a detailed understanding of naturally occurring and socially situated cognition. This is one way to gain an understanding of socially-situated numeracy practices.

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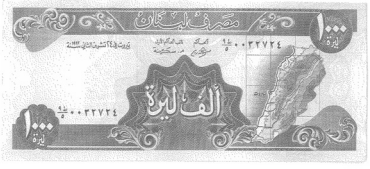
Appendix A

Stimulus Types for the Bill and Numeral Recognition and Priming Task

Examples of two standard bills. The relative sizes of the bills were preserved.

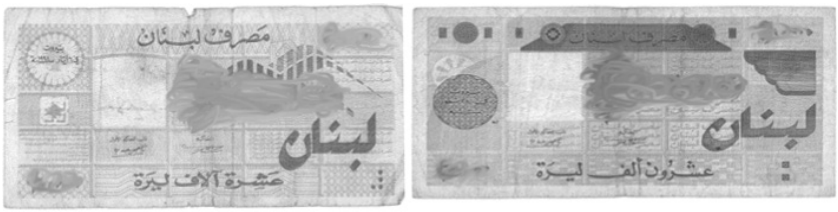
1000 LL



5000 LL

Examples of two numeral occluded bills

10 000 LL 20 000



Example of currency numeral only bill

50 000 LL

Appendix B

Analysis of Variance Tables for Bill and Numeral Recognition Study

Main effects	
Selling practice	F (1,35)= 33.188, P<0.001
Numeracy practice	F (1,35)= 13.51, P<0.001
All bills (repeated measure)	F (1,35)= 99.025, P<0.001
Interaction effects	
All bills×selling practice	F (1,35)=5.82, P<0.001
All bills×numeracy practice	F (1,35)= 6.09, P<0.001
Selling×numeracy practice	F (1,35)= 1.220, not significant
All bills×selling practice×numeracy practice	F (1,35)= 5.59, P<0.05