Telling Time from Analog and Digital Clocks

A Multiple-Route Account

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Abstract. Does the naming of clocks always require conceptual preparation? To examine this question, speakers were presented with analog and digital clocks that had to be named in Dutch using either a relative (e.g., "quarter to four") or an absolute (e.g., "three forty-five") clock time expression format. Naming latencies showed evidence of conceptual preparation when speakers produced relative time expressions to analog and digital clocks, but not when they used absolute time expressions. These findings indicate that conceptual mediation is not always mandatory for telling time, but instead depends on clock time expression format, supporting a multiple-route account of Dutch clock time naming.

Keywords: clock time naming, conceptual mediation, analog clock, digital clock

Whether Arabic numerals can or cannot be named without first activating their meaning is a central topic in the domain of numerical cognition. For the naming of objects, there exists good evidence that conceptual mediation is always required (Levelt, Roelofs, & Meyer, 1999; Damian, Vigliocco, & Levelt, 2001). However, some models of single-digit Arabic numeral naming argue in favor of obligatory conceptual mediation (McCloskey, Caramazza, & Basili, 1985; Brysbaert, 1995; Damian, 2004), whereas others advance a dual-route account in which Arabic numerals can also be named without conceptual access (Deloche & Seron, 1987). After an extensive review of the literature, Ratinckx, Brysbaert, and Fias (2005) recently concluded that single-digit Arabic numerals, like words (e.g., Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001), can be named nonconceptually, via direct form-connections between the digital input and the verbal output.

In line with this dual-route account, differences in the involvement of conceptual preparation are observed when multi-digit Arabic numbers have to be named. Whether a three-digit Arabic number is named as a house number (e.g., 245, say "two hundred forty-five") or as a clock time (e.g., 2:45, say "quarter to three") determines the need of conceptual preparation. Naming latencies in Dutch are influenced by form encoding factors, such as utterance length and frequency, when house numbers have to be produced, whereas latencies show evidence of additional conceptual involvement when clock times have to be produced (Meeuwissen, Roelofs, & Levelt, 2003). Thus, house number naming, like single-digit Arabic numeral naming and word reading, can be achieved without conceptual access. In contrast, clock time naming in Dutch obligatorily requires conceptual mediation, like object naming.

The requirement of conceptual mediation in clock time naming results from the way time is commonly told in Dutch. Most Dutch speakers adopt a relative time telling system for describing analog and digital clocks. For example, they say "tien over vijf" (translated "ten past five") to 5:10 or "kwart voor vier" (translated "quarter to four") to 3:45. Unlike American English, which uses an hourly reference point for time telling, a secondary, half-hourly reference point is used in Dutch, which operates between twenty and forty minutes past the hour, yielding expressions like "tien voor half vier" (translated "ten before half four") to 3:20. Importantly, the mapping of the digital time information onto the clock time expression is not transparent and requires conceptual transformations.

On the basis of earlier findings of conceptual mediation in Dutch clock time naming (Meeuwissen et al., 2003; Korvorst, Roelofs, & Levelt, 2006), we developed a model for Dutch time telling, outlined in Figure 1. Three stages of speech planning are distinguished: Conceptual preparation, lemma retrieval and syntax, and form encoding. Conceptual preparation involves determining the hourly or half-hourly reference point and the distance in minutes. Lemma retrieval and syntax concerns selection of corresponding

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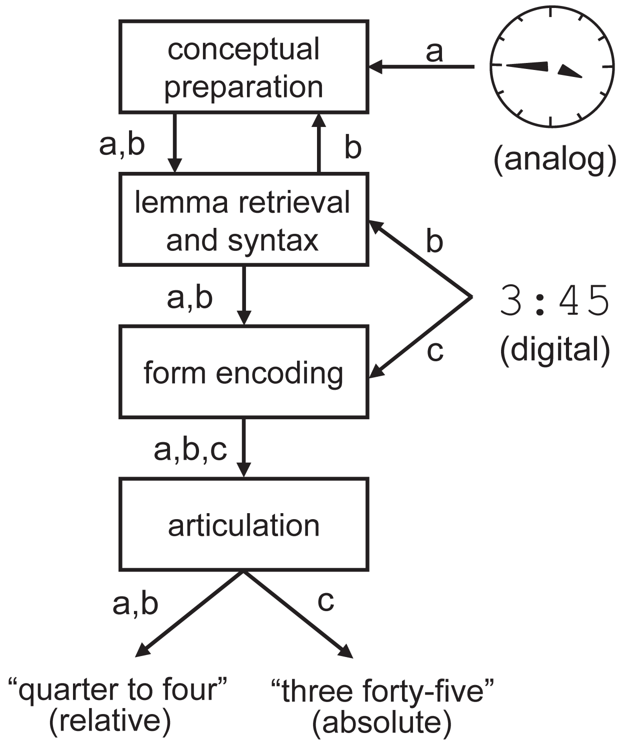

Figure 1. Planning routes in the naming of analog and digital clocks (acc. to Korvorst et al., 2006). Telling relative time from analog clocks proceeds from identifying the hands of the clocks to conceptual preparation, lemma retrieval and syntax, and form encoding (Route a). Telling relative time from digital clocks proceeds from identifying the digits, via lemma access (e.g., accessing *forty*) to conceptual preparation, followed by lemma retrieval (e.g., retrieving *quarter*) and syntax, and form encoding (Route b). Telling absolute time from digital clocks proceeds directly from identifying the digits to form encoding (Route c).

lemmas and putting them in the correct serial order. In the final stage, form encoding, the morphemes and phonemes are retrieved, the phonemes are syllabified, and an articulatory program for the utterance is constructed. Finally, the articulatory program is executed.

Several predictions about Dutch clock time naming can be derived from this functional framework. First, although digital and analog clocks differ in the way they access the planning architecture (see Figure 1), naming digital and analog clocks using a relative time format share conceptual preparation processes (Routes a and b in Figure 1). Support for a shared conceptual preparation stage for relative time telling from analog and digital clocks comes from recent findings on conceptual priming (Meeuwissen, Roelofs, & Levelt, 2004). Although the initial uptake of time information differs for analog and digital clock displays (i.e., determining the positions of big and small hands versus reading the digits in the positions of the hour and the minutes), once extracted, the subsequent conceptual transformation of that information can be carried out in an equivalent manner. Second, no need for conceptual mediation exists for absolute time telling from digital clocks in Dutch. Like Arabic numeral naming (Ratinckx et al., 2005; Korvorst et al., 2006), it suffices to read out the digits in a left-to-right order, retrieve the corresponding morphemes, and phonemes, to syllabify the phonemes, and to construct and execute the articulatory program (Route c in Figure 1).

The aim of the current study was to test these predictions concerning conceptual mediation in clock time naming. We asked speakers to produce relative time expressions (e.g., "quarter to four") in response to analog and digital clocks, and in addition, to produce absolute time expressions (e.g., "three forty-five") in response to digital clocks. We did not ask for the production of absolute time expressions in response to analog clocks, since these would be a strain for Dutch speakers. Importantly, if evidence is obtained for conceptual mediation in relative naming of analog and digital clocks, but not in the absolute naming of digital clocks, then our multiple-route model of Dutch clock-time naming is supported.

Method

Participants

The experiment was conducted with 18 participants randomly selected from the pool of the Max Planck Institute. All participants were young adult native speakers of Dutch and were paid for their participation.

Materials

Stimuli consisted of analog and digital clock displays, as illustrated in Figure 1. Analog clocks were tick-marked and had parametric hour hands. For both analog and digital clocks only "standard" clock times were used, ranging from 2:00 to 9:55, in steps of five minutes (following Meeuwissen et al., 2003; Korvorst et al., 2006). This yielded 12 different clock time *types* consisting of 8 clock times each.

Design

There were three experimental blocks, each testing one *mode* (i.e., analog relative, digital relative, and digital absolute). In each block, the 96 stimuli (12 types × 8 instances) were randomly presented, with 3 repetitions, yielding 288 trials in total. A practice block of 6 trials preceded each experimental block. Each participant was tested on all types and modes. The order of the three modes was counterbalanced across participants.

Table 1. Mean naming latencies (*M*, in ms), standard deviations (*SD*), and percentage errors (E%) per mode and type

Type	Mode								
	Analog relative			Digital relative			Digital absolute		
	M	*SD*	*E%*	*M*	*SD*	*E%*	*M*	*SD*	*E%*
00	976	279	11.3	576	102	4.6	477	109	1.6
05	988	289	6.0	619	121	3.7	472	105	3.0
10	998	277	9.3	631	127	6.3	481	116	3.0
15	964	285	7.6	625	122	3.0	487	118	2.5
20	1054	277	15.5	748	212	8.6	482	110	2.5
25	1032	295	8.1	692	155	4.6	488	117	2.5
30	1025	249	15.5	670	151	5.3	486	108	2.8
35	1029	272	7.2	675	158	5.6	492	109	7.2
40	1047	287	12.5	759	196	12.7	482	115	3.2
45	1018	300	7.2	679	138	4.6	487	109	3.5
50	1026	291	10.4	706	167	11.1	484	111	3.5
55	1037	277	14.6	673	138	6.3	486	118	3.2
Total	1016	283	10.4	670	159	6.4	484	112	3.2

Procedure

Participants were tested individually, while seated in a dimly lit soundproof cabin, in front of a computer monitor (NEC Multisync) and a Sennheiser microphone. The distance between participant and screen was approximately 50 cm. The experiment was run with the NESU experimental software developed at the Max Planck Institute. Preceding each experimental block, participants were provided with an explicit instruction stating how the clocks had to be named (i.e., adopting either the relative or absolute time telling system). Naming latencies were measured using a voice key. Voice key artifacts were diminished by instructing participants to speak fluently and start each response with the same word *om* ("at"), e.g., "om twee uur" ("at two o'clock"). In this way, all responses started with the same phoneme.

On each trial the participant first saw a fixation cross for 200 milliseconds, directly followed by the display of either an analog or a digital clock. Stimuli were presented in white on a black background. Previous work has shown that analog clocks are responded to about 1.5 to 2 times slower than digital clocks (Bock, Irwin, Davidson, & Levelt, 2003). Therefore, in our study, analog clocks were presented for 4 seconds and digital clocks for 2 seconds, leaving speakers enough time to plan and start articulating. An experimental session testing all three modes lasted about 1 hour.

Analyses

The experimenter scored a response as invalid when a speech error occurred, when the voice key was triggered incorrectly, when a time-out occurred, or when a wrong clock time description was given. Invalid trials were subsequently excluded from the statistical analyses. Naming latencies and errors were submitted to by-participant (F_1) and by-item (F_2) analyses of variance (ANOVA) with variables mode and clock time type. Interactions of mode and type were further explored through multi-level multiple regression analyses on the total data set.

Results

Table 1 gives the mean naming latencies, the standard deviations, and the error percentages for the three modes (i.e., analog relative, digital relative, and digital absolute).

Errors depended on mode, $F_1(2, 34) = 12.65$, $p < .001$, $F_2(2, 168) = 84.28$, $p < .001$. More errors were made when producing relative time expressions from analog clocks (10.4%) than from digital clocks (6.4%), and the fewest errors were made when producing absolute time expressions from digital clocks (3.2%), see Table 1. Furthermore, errors depended on clock time type, $F_1(11, 187) = 4.14$, $p < .001$, $F_2(11, 84) = 4.88$, $p < .001$. Furthermore, the effect of clock time type varied with mode, $F_1(22, 374) = 3.71$, $p < .001$, $F_2(22, 168) = 3.39$, $p < .001$. As indicated by Table 1, most errors were made in the slowest conditions, so there is no evidence for a speed-accuracy tradeoff.

Naming latencies also depended on mode, $F_1(2, 34) = 96.17$, $p < .001$, $F_2(2, 168) = 5940.443$, $p < .001$. Naming latencies were slower when producing relative time expressions from analog clocks than from digital clocks, and producing absolute expressions from digital clocks was achieved the quickest. Moreover, latencies depended on clock time type, $F_1(11, 187) = 21.14$, $p < .001$, $F_2(11, 84) = 17.09$, $p < .001$. Furthermore, the effect of clock time type varied with mode, $F_1(22, 374) = 8.79$, $p < .001$, $F_2(22, 168) = 4.84$, $p < .001$.

To further explore this interaction between mode and clock time type, we fitted multilevel multiple regression models (Pinheiro & Bates, 2000; see also Lorch & Myers, 1990) to the data, with the logarithm of naming latencies as dependent variable and participant as error stratum. First, the total set of predictor variables was entered and it was assessed which made a major contribution; in a second step, we constructed the best-fitting model for each mode. Two groups of predictor variables were entered into the analyses (identical to Korvorst et al., 2006): (1) *conceptual factors*: (a) number magnitude [overall magnitude of the clock time and its logarithm], (b) utterance referent [i.e., full hour, half hour, or coming hour], and (c) distance from referent [i.e., 0, 5, 10, or 15 minutes]; (2) *form encoding factors*: (a) utterance length [number of morphemes, phonemes, and syllables], (b) frequency [logarithm of morpheme frequency, i.e., cumulative frequency of all morphemes in the clock time expression, estimated from CELEX database, Baayen, Piepenbrock, & Gulikers, 1995; and logarithm of whole-form frequency, estimated from 89 issues of the Dutch newspaper TROUW from the year 1994].

Relative Naming of Analog Clocks

The best-fitting regression model included both conceptual and form encoding predictors. Naming latencies were determined by utterance referent, $t(4555) = 8.90$, $p < .0001$: Utterances referring to the full hour (i.e., 00, 05, 10, and 15) were named much faster than utterances referring to the half hour (i.e., 20, 25, 30, 35, and 40) and the coming hour (i.e., 45, 50, and 55). Furthermore, a higher log morpheme frequency (cumulative frequency of all morphemes) led to longer naming latencies, $t(4555) = 2.59$, $p < .01$. All effects remained significant after partialing out the variance contributed by the other predictor, $p < .01$. The standard deviation of the residual error in the model was 0.187. The correlation between the observed and predicted naming latencies was .68, indicating a multiple R^2 of 47%. Adding an extra group of predictor variables did not significantly increase the amount of variance accounted for. These multiple regression results indicate that conceptual and form levels of planning are engaged in relative clock time naming from analog clocks.

Relative Naming of Digital Clocks

The best-fitting regression model included both conceptual and form encoding predictors. Naming latencies were modulated by utterance referent, $t(4805) = 22.54$, $p < .0001$, in a similar way as found for relative naming from analog clocks. In addition, the distance in minutes from the referent was a significant predictor, $t(4805) = 7.44$, $p < .0001$, i.e., naming latencies monotonically increased with a greater distance. Furthermore, a greater log morpheme frequency led to longer naming latencies, $t(4805) = 4.47$, $p < .0001$. All effects remained significant in sequential analyses of variance, after partialing out the variance contributed by the other two variables, $p < .001$ for all analyses. The standard deviation of the residual error in the model was 0.170. The correlation between the observed and predicted naming latencies was .63, indicating a multiple R^2 of 40%. Adding an extra group of predictor variables (e.g., overall magnitude and its logarithm) did not significantly increase the amount of variance accounted for. These multiple regression results suggest that for relative clock time naming from digital clocks both conceptual preparation (i.e., determining the utterance referent and the distance in minutes) and form encoding is required, replicating our previous findings (Korvorst et al., 2006).

Absolute Naming of Digital Clocks

In contrast, the best-fitting model for absolute naming only included a form encoding predictor, i.e., utterance length. More specifically, longer clock time expressions elicited longer naming latencies, $t(4989) = 2.92$, $p < .01$. The standard deviation of the residual error in the model was 0.170. The correlation between the observed and predicted naming latencies was .65, indicating a multiple R^2 of 42%. Adding an extra group of predictor variables (i.e., conceptual encoding predictors) did not significantly increase the amount of variance accounted for. These multiple regression results indicate that form encoding suffices for producing absolute clock time expressions from digital clocks in Dutch, in contrast to relative clock time naming.

Summary and Conclusion

In this study we examined whether clocks can be named without conceptual mediation. Speakers of Dutch were presented with analog and digital clocks that had to be named using either relative (e.g., "quarter to four") or absolute (e.g., "three forty-five") utterance formats. Absolute clock time naming from digital clocks was achieved the quickest and elicited the least amount of errors, followed by relative clock time naming from digital and analog clocks, respectively. These differences in naming speed and accuracy are explained by our model of clock time naming with regard to the routes of speech planning involved.

Relative clock time naming from analog and digital clocks demands conceptual preparation and form encoding, like object naming. This involves determining the hourly or half-hourly time referent and distance in minutes by transforming the clock time information from the input, and preparing the lemmas, morphemes, phonological segments, and articulatory program for articulation (Routes a and b in Figure 1). In contrast, absolute clock time naming from digital clocks does not require conceptual preparation but only form encoding, and can be achieved through a nonconceptual conversion route (Route c in Figure 1), similar to Arabic numeral naming (Ratinckx et al., 2005, Roelofs, 2006).

To conclude, our study shows that speakers follow a conceptual planning route when telling time in a relative manner from analog and digital clocks, whereas a faster nonconceptual route is taken when telling time using absolute expressions from digital clocks. Paralleling the difference in conceptual mediation between object naming and word reading (Levelt et al., 1999; Coltheart et al., 2001), our findings lend support to a multiple-route account of Dutch clock time naming. Evidently, speakers can tell the time without having to know what time it is.

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References

Baayen, R.H., Piepenbrock, R., & Gulikers, L. (1995). *The CELEX lexical database (CD-ROM).* Linguistic Data Consortium, University of Pennsylvania, Philadelphia, PA.

Bock, K., Irwin, D.E., Davidson, D.J., & Levelt, W.J.M. (2003). Minding the clock. *Journal of Memory and Language, 48,* 653–685.

Brysbaert, M. (1995). Arabic number reading: On the nature of the numerical scale and the origin of phonological recoding. *Journal of Experimental Psychology: General, 124,* 434–452.

Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Ziegler, J. (2001). DRC: A dual route cascaded model of visual word recognition and reading aloud. *Psychological Review, 108,* 204–256.

Damian, M.F., Vigliocco, G., & Levelt, W.J.M. (2001). Effects of semantic context in the naming of pictures and words. *Cognition, 81,* B77–B86.

Damian, M.F. (2004). Asymmetries in the processing of Arabic digits and number words. *Memory and Cognition, 32,* 164–171.

Deloche, G., & Seron, X. (1987). Numerical transcoding: A general production model. In G. Deloche & X. Seron (Eds.), *Mathematical disabilities: A cognitive neuropsychological perspective* (pp. 137–170). Hillsdale, NJ: Erlbaum.

Korvorst, M., Roelofs, A., & Levelt, W.J.M. (2006). Incrementality in naming and reading complex numerals: Evidence from eyetracking. *The Quarterly Journal of Experimental Psychology, 59,* 296–311.

Levelt, W.J.M., Roelofs, A., & Meyer, A.S. (1999). A theory of lexical access in speech production. *Behavioral and Brain Sciences, 22,* 1–38.

Lorch Jr., R.F., & Myers, J.L. (1990). Regression analyses of repeated measures data in cognition research. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16,* 149–157.

McCloskey, M., Caramazza, A., & Basili, A. (1985). Cognitive mechanisms in number processing and calculation – Evidence from dyscalculia. *Brain and Cognition, 4,* 171–196.

Meeuwissen, M., Roelofs, A., & Levelt, W.J.M. (2003). Planning levels in naming and reading complex numerals. *Memory and Cognition, 31,* 1238–1248.

Meeuwissen, M., Roelofs, A., & Levelt, W.J.M. (2004). Naming analog clocks conceptually facilitates naming digital clocks. *Brain and Language, 90,* 434–440.

Ratinckx, E., Brysbaert, M., & Fias, W. (2005). Naming two-digit Arabic numerals: Evidence from masked priming studies. *Journal of Experimental Psychology: Human Perception and Performance, 31,* 1150–1163.

Roelofs, A. (2006). Functional architecture of naming dice, digits, and number words. *Language and Cognitive Processes, 21,* 78–111.

Pinheiro, J.C., & Bates, D.M. (2000). *Mixed-effects models in S and S-PLUS* (Statistics and Computing). New York: Springer.

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