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Abstract. This paper deals with the study of the kinematic dimension of scribbling activities executed by kindergarten children aged from 3 to 6 years old from three grades. For this purpose, three sigma-lognormal features, six classical ones and one hybrid feature related to visuo-motor skills are extracted from scribbles realized using five different Type Grib. The statistical analysis of these data illustrates that sigma-lognormal modeling can satisfactorily reconstruct kindergarten children's scribbles. Moreover, this preliminary study confirms that there are significant differences between grades with respect to six of the features we studied, regardless of the nature of the scribbling movement made by children. These features are related to rapidity, fluidity and precision of linear and curvilinear movements used for scribbling tasks.

1. Introduction

Scribbling is a spontaneous graphical ability manifested by children in early childhood. According to Lurcat (1988), children acquire this pre-writing ability when they are about 18 months old. Families do not systematically encourage this first manifestation of interest for graphical expression on all accessible surfaces. It is also not systematically given attention in kindergarten, where programming must focus on preparing children to learn handwriting.

In French and Kriol respectively, words like *gribouillage* and *makakri*, used to refer to children's scribbles, have an inherent negative connotation. Moreover, they reveal adults' judgments regarding scribbles, which are essentially related to the esthetics and meaning of the trace which is produced on the surface chosen by the young scribbler. The motor dimension of scribbling is neglected.

However, we hypothesize that scribbling process can provide relevant and useful information on the development of young children's early abilities to control their graphical movements and on the progress of their hand-eye coordination skills. For a first verification of this hypothesis, we carried out a four-month longitudinal experiment in a kindergarten school, entitled "*Y a t'il un copilote à bord* ?" ("Is there a co-pilot on board?").

This paper studies the kinematic dimension of various categories of scribbling movements which were recorded during the study. Its purpose is to determine if such dimensions can help distinguish between the levels of movement control achieved by kindergarten children according to their grade, regardless of the Type Grib. In section 2, we provide information on the participants, the tasks and the experimental conditions. In section 3, we details the feature extraction process. In section 4, the preliminary results of the statistical analysis of six classical kinematic features and four sigma-lognormal features are discussed. These results are related to 2 questions: Can sigma-lognormal modeling satisfactorily reconstruct children's scribbles? Do the values taken by some classical or sigma-lognormal features depend on kindergarten grade, or do they depend on the scribbling strategies?

2. Participants, tasks and conditions of realization

Sixty children took part in this experiment, from three kindergarten grades called '*Petite Section*' (PS), '*Moyenne Section*' (MS) and '*Grande Section*' (GS). Table 1 shows their distribution by gender and grade. PS pupils were 3-4 years old. They had 6 months of graphomotor preparation lessons (during classroom), while MS ones were 4-5 years old with 18 months of preparation. GS pupils were 5-6 years old with 30 months of preparation lessons.

Table 1. Distribution of participants according to gender (F, M) and grade (PS, MS, GS).

	GS	MS	PS	Total
F	12 (20%)	9 (15%)	8 (13%)	29 (48%)
M	17 (28%)	4 (7%)	10 (17%)	31 (52%)
Total	29 (48%)	13 (22%)	18 (30%)	60 (100%)

Each child was brought from their classroom to the experiment room by the accompanying experimenter. The child was asked to execute five scribbles according various Type Grib: S1, S2, S3, S4 and S5. The first one was spontaneous (S1) without any constraint on the type of movement. The second scribble (S2) was to produce only linear strokes all over the sheet of paper. The third (S3) was the same as S2, but the pupil was asked to draw as fast as he could. Next, for the S4 and S5 tasks, the children were asked to use only curved movements to draw their scribbles all over the sheet of paper and S5 had to be realized faster than S4.

For each of these productions, the pupil was asked to begin their scribble when they heard a randomized audio signal. They were asked to produce 20 seconds of scribbling trying to keep the pen down for the entire period. During the online acquisition of the child's scribbling movements, the experimenter took a seat in front of a computer and the child sat in front of a digitizing tablet according to the configuration shown in Figure 1. The experimenter verified that the child was correctly seated and that they felt comfortable writing on the tablet.

Figure 1. Workstation used at the kindergarten for the experiment session

To ensure that the task had been properly understood, the experimenter showed the requested movement with his fingertip systematically before each child had to execute a new Type Grib. The numbers of scribbles, which were recorded for each condition, are provided in Table 2.

Table 2. Numbers of scribbles recorded by grade and gender for each condition: S1, S2, S3, S4 and S5.

Type Grib	GS		MS		PS		All grades
	F	M	F	M	F	M	
S1	12	16	9	4	8	10	59
S2	11	15	6	3	6	9	50
S3	11	17	9	3	7	9	56
S4	12	17	8	4	7	10	58
S5	11	17	8	4	8	9	57
All types	57	82	40	18	36	47	280

3. Feature extraction from scribbles

In the present study, we focus on two sets of features that can be called the classical dynamic set and the sigma-lognormal set. The extraction process is illustrated in Figure 2. First, for each scribble, the raw data are digitized by the *Wacom Intuos* tablet with a sampling rate of 200 Hz. The pressure $p(t)$ and the two-dimensional position *(x(t), y(t))* of the pen tip are recorded using *DekatTras* software for 10 seconds from the fifth second of scribbling. Next, on the basis of these raw data, six classical features are computed.

Figure 2 provides also the names of the classical features in bold fonts and those of the sigma-lognormal in Italics. The six classical features correspond respectively to (1) the length of the trajectory of the pen tip on the surface of the tablet, (2) the surface scribbled by the child, (3) the value of the pen-up duration, (4) the number of velocity peaks, (5, 6) the values of the maximal and minimal pressure on the pen tip. These features have already shown their usefulness in characterizing the degree of visuo-motor maturation (Rosemblum et al. 2003, Chartrel and Vinter 2010).

Then, the preprocessing software is used to convert the raw date file into HWS format. The *ScriptStudio* software uses these inputs to estimate three sigma-lognormal features. As illustrated in Figure 3, *ScriptStudio* conducts sigma-lognormal modeling which describes the velocity of planar movements (e.g. handwritten trajectories) as a vector summation of neuromuscular components that have a weighted and time-shifted lognormal velocity profile and a circle-arc trajectory. The mathematical definition of this model has been described and explained numerous times. Interested readers can refer to the relevant technical publications for mathematical details (Plamondon and Djioua 2006, O'Reilly and Plamondon 2009).
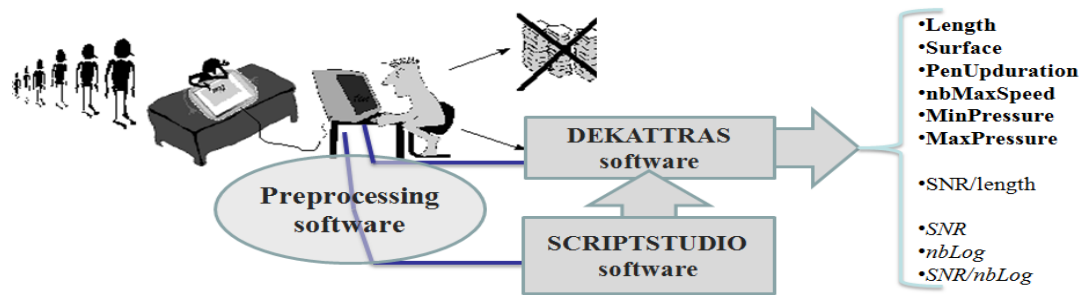
Figure 2. Feature extraction process. Bold type indicates classical features, Italic font indicates sigma-lognormal features and Roman type indicates hybrid feature.

Our analyses used features extracted from this segmentation process: the signal-to-noise ratio of the reconstruction process (O'Reilly and Plamondon 2009), the number of basic lognormal strokes used for modeling (*nbLog*), and the ratio of these two variables (*SNR/nbLog*). This last variable reflects the writer's ability to make regular movements. It is a good global indicator of the graphomotor performance of a given writer. Altogether, these variables are considered to index the lognormality of the produced movements, a concept similar to movement smoothness (Plamondon et al 2013).

Lastly, we have introduced a new feature which is built from a classical one and a sigma-lognormal one. It is the SNR ratio divided by the length of the trajectory produced by the inking pen tip on the sheet of paper.
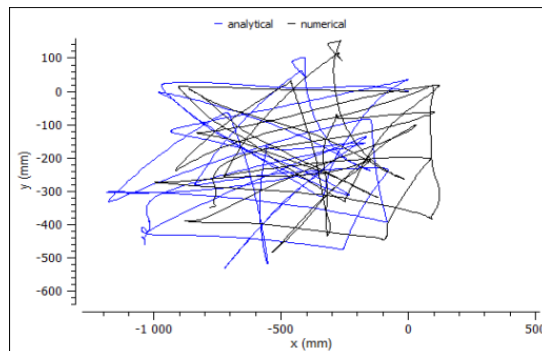

Figure 3. Example of a child' scribble (in blue) and its Sigma-Lognormal reconstruction (in black).

4. Statistical analysis of the features

ANOVA tests, Kruskal-Wallis tests and PCA analyses were carried out on the dataset consisting of 10 features in order to respond to the questions considered in the introduction section. Results are presented in the followings.

4.1 Reconstructing children' scribbles using Sigma-lognormal modeling

To answer the first question (Can sigma-lognormal modeling satisfactorily reconstruct children's scribbles?), we calculated the SNR histogram for all the scribbles (Figure 4). This distribution corresponds to SNR values before correction of the speed values at the beginning and the end of the truncated 10-second signal. 85% of the scribbles have an SNR greater than 15db and 58% of them have an SNR greater than 18db. The 15dB value has often been judged as sufficient to analyze elderly adults with declining handwriting (Plamondon et al. 2013, Woch et al 2011) and young children's productions of pattern movements (Duval et al. 2013). On this basis, we used the same threshold here to produce our statistical study of the behaviours of the sigma-lognormal features in conjunction with the classical ones.

4.2 Grade and on Type Grib impact features

The non-parametric and parametric statistical tests used to study the effects of the two factors, Grade and Type Grib, with respect to the 10 classical and sigma-lognormal features, reveal a significant effect for most of those features. Besides, systematically, when an effect of Type Grib is significant, grade has a significant effect too.
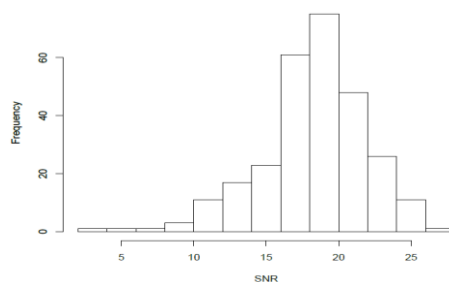
Figure 4. SNR distribution.

Table 3. Significance of features (x = significant effect, NS = non-significant effect)

Test	Factor	SNR	NbLog	SNR/Length	surface	SNR/NbLog	Length	nbPenUp	nbMaxSpeed	minPressure	maxPressure
ANOVA	Grade	x	x	x	x	x	x	x	NS	NS	NS
Kruskal-Wallis	Grade	x	x	x	NS	x	x	x	x	x	x
ANOVA	Type Grib	x	x	x	NS	x	x	x	NS	NS	NS
Kruskal-Wallis	Type Grib	x	x	x	NS	x	x	x	x	NS	x
		4/4	4/4	4/4	1/4	4/4	4/4	4/4	2/4	1/4	1/4

5. Conclusion and perspectives

In this paper, we first showed that sigma-lognormal modeling can provide satisfactory reconstructions of scribbles produced by young children in kindergarten. This observation constitutes a preliminary result that may help us design studies of the kinematic stability of various Type Grib taking into account a similar sigma-lognormal approach (Pirlo et al. 2013). Moreover, for six features related to fundamental dynamic abilities such as rapidity, fluidity and precision of fine movements, our analysis shows that there are significant differences between grades and that there are also significant differences from one scribbling strategy to the next. Future research includes analysis of how gender impacts all these abilities.

Scribbling ability is not yet used in kindergarten as an objective way to assess children's graphomotor skills for teaching purposes. The preliminary results of our study "*Y a t'il un copilote à bord?*" may inspire further studies about the potential relevance of graphomotor training for very young children. One of the main points of interest relative to graphomotor training tasks is that it is not necessary for a child to have a well-developed socio-linguistic background to be able to scribble. Moreover, it is a familiar activity that can be carried out by children starting in the first grade of kindergarten regardless of the child's language and linguistic background.

With this in mind, we launched a three-year longitudinal experiment in January 2015 in an experimental preschool structure called "*Lakou TiFilawo: le bon Départ*" ("the good start").

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