Comparison Between Two Sigma-Lognormal Extractors with Primary Schools Students Handwriting

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Abstract. In this study, we examine the differences between two Sigma-Lognormal extractors. ScriptStudio is used to extract the Sigma-Lognormal parameters based on the velocity, and iDeLog is used for extracting the parameters based on both the velocity and the trajectory. The iDeLog software is tested with and without smoothing the data. Handwriting data are used to compare both types of extractor (algorithm for parameters extraction). The data consist of triangles drawn on a Wacom Cintiq 13HD by healthy children aged between six and thirteen years old. Globally, ScriptStudio Extract the data with the best SNR for the trajectory (SNRt) and the velocity (SNRv). Moreover, it used slightly more lognormals for the reconstruction than iDeLog with smoothing (iDeLog ws), and nearly half of the number of lognormals used in iDeLog without smoothing (iDeLog ns). Finally, iDeLog without smoothing has a better reconstruction of the velocity and the trajectory than iDeLog with smoothing.

Keywords: Sigma-lognormal model · Kinematic theory of human movements · Kinematic analysis · Fine motor control · Children handwriting · ScriptStudio · iDeLog

1 Introduction

The study of human movements can be useful to understand the impact of some psychophysical conditions on the human motor control as for example in studies dealing with children suffering from Attention Deficit Disorder, with or without Hyperactivity (ADHD) [1, 2]. In that case, different approaches have been proposed in order to model this neurological problem, among these stands the Kinematic Theory of rapid human movements [3–7]. This theory describes the generation of human movements as the results of a synergetic action of a large number of different coupled subsystems organized into neuromuscular systems. The central nervous system plans the movement to be executed by the peripheral system. Overall, the impulse response of a neuromuscular system is described by a lognormal function and the resulting velocity of an activation

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command can be modelled with a vector summation of lognormals. According to the lognormality principle, the Kinematic Theory describes movements executed under an adequate motor control. Thus, during the development of children, these will improve their motor control and will tend to the lognormality while become adult [8].

The Kinematic Theory is the corner stone of the Sigma-Lognormal model that can shape complex and underdeveloped children movements. This model assumes that the velocity of a human movement can be modelled using lognormal functions combined by a time superimposed vector addition. Each lognormal is described by six parameters [9]. Several software have been developed over the years to perform reverse engineering and extract these Sigma-Lognormal parameters from various movements. Among them, there are ScriptStudio [9] and iDeLog [10]. Those two used different approaches to extract the parameters. The first one is mostly based on the velocity analysis, while the second one seeks a trade-off between the velocity and the trajectory to recover the best fitting parameters. In this study, we aim to compare the effectiveness of both software to extract the Sigma-Lognormal parameters from primary school students handwriting who were asked to execute complex movements, some triangles, on a tablet. Thereupon, we will first present two software used in this study in Sect. 2. Afterward, in Sect. 3, the methodology and the dataset used to compare them will be presented. Then, in Sect. 4, the statistical analyses that were carried out and their results will be detailed. Finally, we will examine and discuss those results in Sect. 5, to put the whole work in a more general perspective.

2 The Extractors

2.1 ScriptStudio Algorithm

ScriptStudio [9] is a Sigma-Lognormal reconstruction software based on the velocity that incorporates the Robust XZERO algorithm [11]. This software extracts the Sigma-Lognormal parameters while maximizing the velocity Signal-to-Noise Ratio (SNRv). This performance criterion is calculated between the original and reconstructed velocity. Specifically, this extractor will use a vector combination of lognormals to reconstruct the original velocity. Thus, in a first step, for each velocity maximum peak in the original velocity profile, the software plugs a lognormal. Afterward, in the next steps, smaller lognormals are added to the reconstructed signal in order to increase the SNRv up to a minimum required SNRv specified by the experimenter. The resulting trajectory is reconstructed by integrating the velocity with no further optimization. This software has proven its value as it has been used in a multitude of studies as detection tool for ADHD [12, 13], brain injury [14, 15], Parkinson [16] and more. Furthermore, it was used to monitor the children evolution towards lognormality [8, 17].

2.2 iDeLog Algorithm

iDeLog [10] reconstructs the trajectory and the velocity of a movement at the same time, calculating the angles and lognormal parameters of each stroke. This algorithm is based on motor equivalence theory and the hypothesis of a visual feedback compatible with open-loop motor control. To this end, firstly, the virtual target points and angles are calculated by finding the velocity minimum and using the 8-connected trajectory of a given long and complex movement. In this way the velocity is decomposed as a sum of weighted lognormals, where the spatial and kinematic parameters are extracted separately. Secondly, with this first segmentation procedure, a first velocity reconstruction is obtained. Then, the reconstructed movement is iteratively optimized by moving the virtual target points with the ensuing changes of the angles and lognormal parameters. Finally, a fine optimization of the virtual target point is carried out for each segment by improving the SNRv and SNRt simultaneously.

2.3 Differences Between Both Extractor

Those two ways of extracting the Sigma-Lognormal model parameters present some differences that can impact the results of this study. First of all, ScriptStudio reconstructs the pen tip velocity by overlapping the lognormals composing the reconstructed signal. As a result, errors in the velocity estimation are propagated over the entire movement, resulting in an increased spatial deviation [18]. To avoid this problem and improve the trajectory reconstruction, iDeLog relies on adjusting the trajectory and speed jointly. So, rather than adding new lognormals to improve the reconstruction, iDeLog iteratively moves the target points to improve the adjustment between an original trajectory and its reconstructed counterpart. However, iDeLog may present lower SNRv compared to ScriptStudio but better SNRt.

As ScriptStudio preprocess the raw signal to break down the speed profile into lognormals, the iDeLog includes an option for preprocessing the original signal or not. This option allows to smooth the input signal in the same way that ScriptStudio does. As a difference in the preprocessing, the sampling frequency is not changed in iDeLog.

3 Methodology

The present study is part of a larger project aiming to standardize the data acquisition system developed within the Scribens Lab. This system, called the lognometer [19], could be used as a diagnostic tool in ADHD detection for example [13].

3.1 Participants

Participants were recruited from three different primary schools. In total, 780 children aged from six years to thirteen years old participated in the research, and from 1st grade to the 6th. For each grade, there are at least 120 participants while the maximum is 135 participants. 48% (375) of the children are female. Moreover, 24% (185) of the participants were neuroatypical. For the present comparative study, the neuroatypical participants were excluded. That left 594 participants remaining with at least 90 children per grade.

3.2 Procedures

Participants were asked to rapidly draw, one at a time, 30 triangles on a digitizing tablet (Wacom Cintiq HD13) using a stylus [19]. The instructions for writing a triangle were composed of three points, one starting and ending dot (1), and two crossing points (2 and 3) to be reached in the corresponding sequence: 1,2,3,1. The guide sheet displayed is presented in Fig. 1. An audio cue signal was used to indicate the start of the drawing. The handwritten data were recorded at 200 Hz.

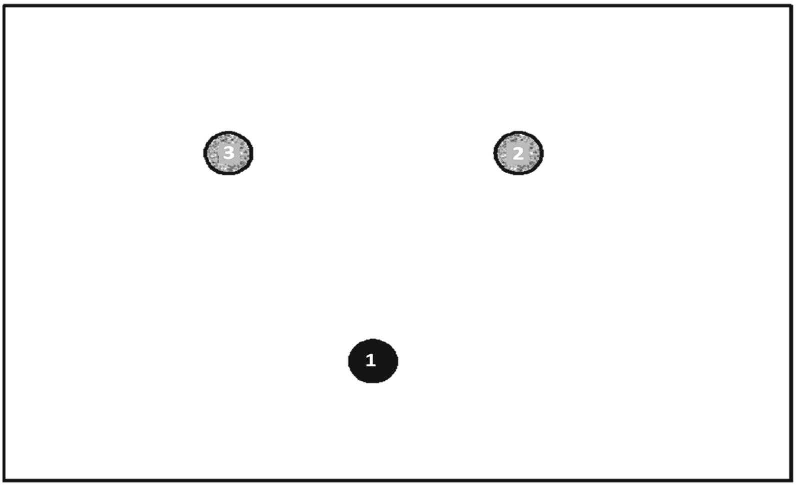

Fig. 1. The guide sheet displayed on the screen of the tablet.

3.3 Sigma-Lognormal Extraction

Before extracting the Sigma-Lognormal parameters, the dataset was cleaned. Thus, the strokes that started before the sound cue or weren't properly executed were removed. Afterward, the three extractors (iDeLog ws, iDeLog ns and ScripStudio) was used to extract the Sigma-Lognormal parameters for each trial. This model allows to extract three global parameters: the number of lognormals (NbLog) and the Signal-to-Noise Ratio for trajectory (SNRt) and for velocity (SNRv). Those parameters are unique for each trial and describe the general state of the neuromotor system. Moreover, we calculated the SNRt/NbLog and SNRv/NbLog. Based on those parameters, we rejected the trials that had a SNRt or SNRv lower than 10 dB, or that required more than 40 lognormals for reconstruction. In those cases, we assumed that the extractors were not able to reconstruct the signal correctly.

4 Results

To compare the three extractors, we analyzed the basic statistics of the above-mentioned global parameters. Table 1 presents the mean and the standard deviation of each parameter for the three extractors. Moreover, the repartition of the parameters is presented in the following boxplots (Fig. 2). We can see that ScriptStudio reconstruct the data with a higher SNRt, SNRv, SNRv\NbLog. iDeLog with smoothing presents the lowest NbLog, SNRt and SNRv. On the other hand, iDeLog with smoothing has the highest SNRt\NbLog. Finally, iDeLog without smoothing has the highest NbLog, and consequently the lowest SNRt\NbLog and SNRv\NbLog. The bold values with upper script “a” and “b” are respectively the highest and lowest value for each parameter.

Table 1. Statistical measures for each extractor.

		Script studio	iDeLog ws	iDeLog ns
NbLog	Mean	8.95	**7.28**[b]	**16.41**[a]
	Std	1.69	1.45	4.09
SNRt	Mean	**30.27**[a]	**24.30**[b]	25.67
	Std	2.52	1.01	1.18
SNRv	Mean	**25.40**[a]	**16.94**[b]	17.87
	Std	0.98	0.98	0.69
SNRt\NbLog	Mean	3.59	**3.65**[a]	**1.80**[b]
	Std	0.55	0.65	0.41
SNRv\NbLog	Mean	**3.05**[a]	2.56	**1.26**[b]
	Std	0.57	0.51	0.32

Table 2. P-value for the statistical tests. First row: the results of the comparison of the 3 algorithms with the non-parametric Kruskal-Wallis test. The following rows: the results of the non-parametric pair comparison with the Mann-Whitney U-test.

	NbLog	SNRt	SNRv	SNRt/ NbLog	SNRv/ NbLog
ScriptStudio iDeLog ws iDeLog ns	**2E−267**	**6E−249**	**1E−279**	**2E−245**	**9E−264**
ScriptStudio iDeLog ws	**2E−66**	**2E−173**	**5E−191**	7E−02	**8E−44**
ScriptStudio iDeLog ns	**2E−172**	**1E−148**	**5E−191**	**6E−187**	**8E−190**
iDeLog ws iDeLog ns	**5E−187**	**2E−77**	**1E−64**	**5E−185**	**1E−180**

For the statistical tests, the Bonferroni correction was used to counteract the multiple comparison. In that case, the α (0.05) was divided by the number of extracted parameters (3) which brought the corrected α to 0.017. After that, we used a Jarque-Bera test [20] to determine if the extracted parameters are normally distributed. In that case, only the SNRt/NbLog and SNRv/NbLog for ScriptStudio and IDeLog with smoothing has a p-value over 0.05, so those parameters are normally distributed. All the other parameters were not normally distributed. According to this observation, we used the Kruskal-Wallis

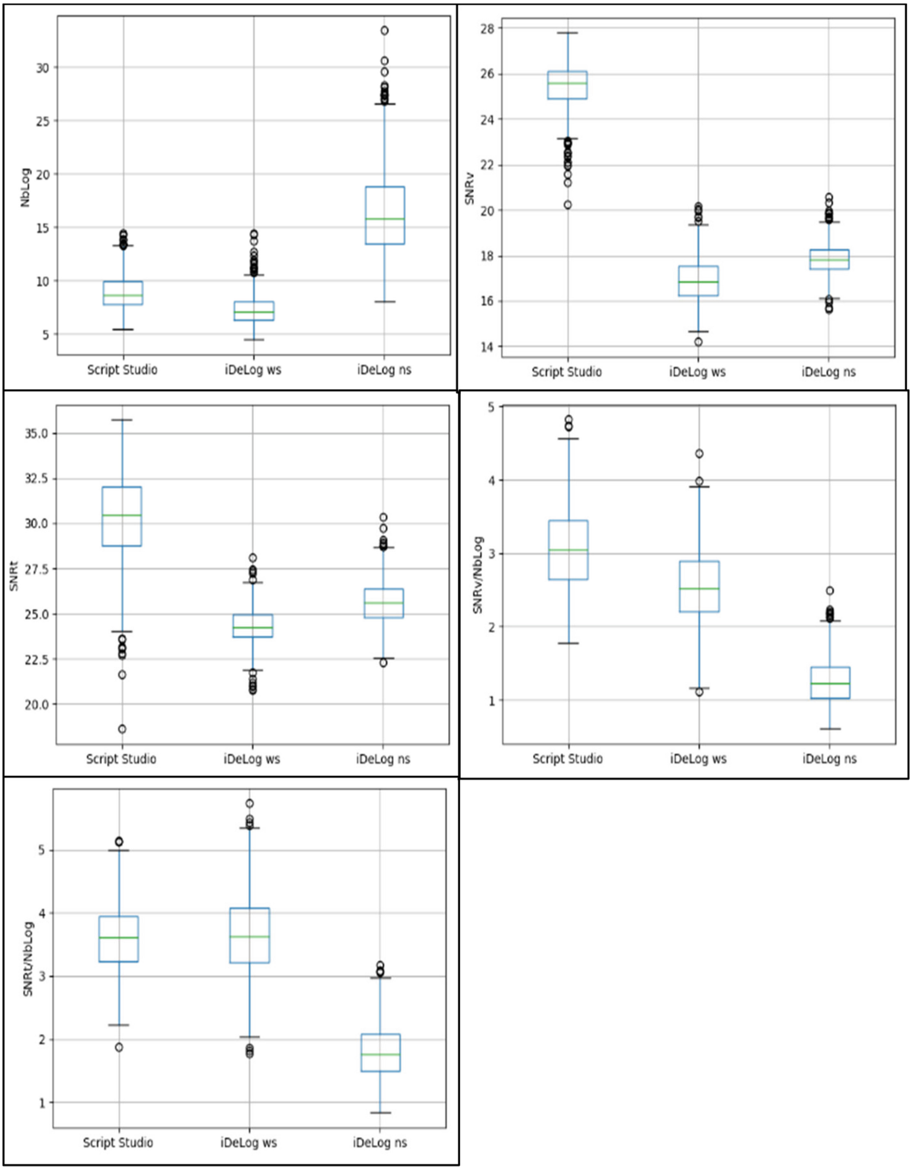

Fig. 2. The boxplot representing the extracted parameters for the three extractors. From top to bottom and left to right: NbLog, SNRt, SNRt\NbLog, SNRv and SNRv\NbLog. In each figure, from left to right: ScriptStudio, iDeLog with smoothing and iDeLog without smoothing.

non-parametric test [21] to evaluate if the three extractors are statistically similar. The extractors are not statistically similar because their p-value lower than the corrected α. When comparing the extractor to each other, we used the non-parametric Mann-Whitney U-test [22]. Thus, there are significant differences between the extractors for all the parameters, except for the SNRt/NbLog between ScriptStudio and iDeLog with smoothing. The p-values and the statistical value of each test are presented in Table 2 and 3. The first row presents the results of the non-parametric Kruskal-Wallis test. The following rows are the results of the non-parametric Mann Whitney U-test. All the bold values in Table 2 represent a p-value lower than the α corrected with Bonferroni (0.017). The statistical value for the Kruskal-Wallis test corresponds to the chi-squared value. The statistical value for the Mann Whitney U-test corresponds to the sum of ranks one samples. For both, the higher the value, the better is the results.

Table 3. The statistical tests value for the non-parametric Kruskal-Wallis test in the first row results of the comparison of the 3 algorithms. The following rows: the results of the non-parametric Mann-Whitney U-test.

	NbLog	SNRt	SNRv	SNRt/ NbLog	SNRv/ NbLog
ScriptStudio iDeLog ws iDeLog ns	1228	1143	1285	1127	1211
ScriptStudio iDeLog ws	69933	8035	0	159181	88901
ScriptStudio iDeLog ns	8457	20056	2	1810	526
iDeLog ws iDeLog ns	1791	61813	71269	2680	4683

5 Discussion

After those results, it seems that ScriptStudio is more suited to extract the global sigma-lognormal parameters of triangles because it gives back a higher SNR than IDeLog for the velocity and the trajectory, while using a lower number of lognormals. Moreover, the SNR/NbLog for the trajectory and the velocity are better for ScriptStudio since that they needed less NbLog than iDeLog without smoothing and having a higher SNR than the iDeLog with smoothing. It must be kept in mind, that this dataset is composed of triangles executed by children that did not reach their full potential yet. In that case, those children are heading towards the lognormality. Concerning the triangles, those movements can be classified as complex but not as long movement. Moreover, the movements executed by those children may be jerkier and not continuous. In that case, it makes sense that iDeLog have poorer results than ScriptStudio since it adds one lognormal per velocity peak. This founding fits with what was reported in [10] where it was mentioned that iDeLog should have better results for continuous, long and complex movement like signatures.

6 Future Works

In conclusion, this preliminary study shows that that both iDeLog and ScriptStudio could be used as a platform to analyze children movements, but that ScriptStudio is might be more appropriate to do it, when the best reconstruction is a requirement. It would be interesting to examine the results of triangles executed by adult to see if the performance of iDeLog improves when the movements are less jerky but this is beyond the scope of this paper. In future works, we will extend our statistical analyses and investigate the classification performance of the three algorithms. We will add the other Sigma-Lognormal parameters to the analyses: t_0, D, Theta start, theta end, μ and σ. Moreover, we will use those results to explore the possibility of discriminating for example between age groups and gender. Although the performances in terms of signal reconstruction might differ, this does not guarantee that their performances in term of classification and prediction will follow a similar ranking Moreover, in the context of the No Free Lunch Theorem [23], it is expected that fine tuning will be required to adapt and optimize any of these algorithms to any specific studies.

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References

1. Yan, J.H., Thomas, J.R.: Arm movement control: differences between children with and without attention deficit hyperactivity disorder. Res. Q. Exerc. Sport **73**(1), 10–18 (2002)
2. Rosenblum, S., Epsztein, L., Josman, N.: Handwriting performance of children with attention deficit hyperactive disorders: a pilot study. Phys. Occup. Ther. Pediatr. **28**(3), 219–234 (2008)
3. Plamondon, R., Yu, L.-D., Stelmach, G.E., Clément, B.: On the automatic extraction of biomechanical information from handwriting signals. IEEE Trans. Syst. Man Cybern. **21**(1), 90–101 (1991)
4. Plamondon, R.: A kinematic theory of rapid human movements: part I: movement representation and generation. Biol. Cybern. **72**(4), 295–307 (1995)
5. Plamondon, R.: A kinematic theory of rapid human movements. Part II. Movement time and control. Biol. Cybern. **72**(4), 309–320 (1995)
6. Plamondon, R.: A kinematic theory of rapid human movements: part III. Kinetic outcomes. Biol. Cybern. **78**(2), 133–145 (1998)
7. Plamondon, R., Feng, C., Woch, A.: A kinematic theory of rapid human movement. Part IV: a formal mathematical proof and new insights. Biol. Cybern. **89**(2), 126–138 (2003)
8. Plamondon, R., O'Reilly, C., Rémi, C., Duval, T.: The lognormal handwriter: learning, performing, and declining. Front. Psychol. **4**, 945 (2013)
9. O'Reilly, C., Plamondon, R.: Development of a sigma-lognormal representation for on-line signatures. Pattern Recogn. **42**(12), 3324–3337 (2009)
10. Ferrer, M.A., Diaz, M., Carmona-Duarte, C., Plamondon, R.: iDeLog: iterative dual spatial and kinematic extraction of sigma-lognormal parameters. IEEE Trans. Pattern Anal. Mach. Intell. **42**(1), 114–125 (2018)
11. O'Reilly, C., Plamondon, R.: Automatic extraction of sigma-lognormal parameters on signatures. In: Proceedings of 11th International Conference on Frontier in Handwriting Recognition (ICFHR) (2008)
12. Laniel, P., Faci, N., Plamondon, R., Beauchamp, M.H., Gauthier, B.: Kinematic analysis of fast pen strokes in children with ADHD. Appl. Neuropsychol.: Child 1–16 (2019)

13. Laniel, P., Faci, N., Plamondon, R., Beauchamp, M., Gauthier, B.: Kinematic analysis of fast pen strokes in children with ADHD using the sigma-lognormal model. In: International Conference on Pattern Recognition and Artificial Intelligence: Workshop on the Lognormality Principle and its Applications, Montreal (2018)
14. Faci, N., Désiré, N., Beauchamp, M.H., Gagnon, I., Plamondon, R.: Lognormality in children with mild traumatic brain injury: a preliminary pilot study. In: International Conference on Pattern Recognition and Artificial Intelligence, Montreal (2018)
15. Faci, N., Désiré, N., Beauchamps, M.H., Gagnon, I., Plamondon, R.: Analysing the evolution of children neuromotor system lognormality after mild traumatic brain injury. In: Lognormality Principle: Applications for e-Security, e-Health and e-Learning, World scientific Publishing (2020, in press)
16. Lebel, K., Nguyen, H., Duval, C., Plamondon, R., Boissy, P.: Capturing the cranio-caudal signature of a turn with inertial measurement systems: methods, parameters robustness and reliability. Front. Bioeng. Biotechnol. **5**, 51 (2017)
17. Duval, T., Plamondon, R., O'Reilly, C., Remi, C., Vaillant, J.: On the use of the sigma-lognormal model to study children handwriting. In: Nakagawa, M., Liwicki, M., Zhu, B. (eds.) Recent Progress in Graphonomics: Learn from the Past, Nara, Japan (2013)
18. Fischer, A., Plamondon, R., O'Reilly, C., Savaria, Y.: Neuromuscular representation and synthetic generation of handwritten whiteboard note. In: Proceedings of the International Conference on Frontiers in Handwriting Recognition (2014)
19. Faci, N., Boyogueno Bibias, S.P., Plamondon, R., Bergeron, N.: A new experimental set-up to run neuromuscular tests. In: International Conference on Pattern Recognition and Artificial Intelligence: Workshop on the Lognormality Principle and its Applications, Montreal (2018)
20. Jarque, C.M., Bera, A.K.: Efficient tests for normality, homoscedasticity and serial independence of regression residuals. Econ. Lett. **6**(3), 255–259 (1980)
21. Kruskal, W.H., Wallis, W.A.: Use of ranks in one-criterion variance analysis. J. Am. Stat. Assoc. **47**(260), 583–621 (1952)
22. Mann, H.B., Whitney, D.R.: On a test of whether one of two random variables is stochastically larger than the other. Ann. Math. Stat. **18**, 50–60 (1947)
23. Wolpert, D.H., Macready, W.G.: No free lunch theorems for optimization. IEEE Trans. Evol. Comput. **1**(1), 67–82 (1997)