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Childhood Apraxia of Speech. Developmental Speech Patterns. A Wide Retrospective Study

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Abstract: *Patterns of a phenomenon define the entity. If one understands the patterns of the maze, he can find his way there. Patterns of colors on a dress will hold its characters and soul. Understanding the expressive patterns of a developmental syndrome enables treating it with success. It is true for treating Childhood Apraxia of speech (CAS) as well. CAS as motor-speech disorder involves difficulties in sounds production for speech purposes. The difficulties can be demonstrated in patterns that would be specific to CAS. These patterns can distinguish one phenomenon from another.*
A retrospective research was conducted based on 277 entry level evaluations of children diagnosed with CAS or suspected of CAS who visited a private clinic between 2006 and 2013. The analysis included speech variables alongside background and environmental variables. This article is dealing with speech patterns of children with motor speech disorder. Among the patterns examined are vowels ladder, single syllable ladder, Blowing and SSP (single sound production), Oral motor and SSP, Consonant group ladder and Consonants Exploratory factor analysis.
The findings demonstrated the relationship and order of vowels, consonants and single syllables among Hebrew speaking children diagnosed with motor speech disorder. The Consonants Exploratory factor analysis gave validity to the existence of unique consonant groups. Further discussion regarding every result and its implication is included. Understanding the unique patterns of consonants and vowels strength among children with CAS can help clinicians in the decision-making process and goals targeting.

Keywords: *childhood apraxia of speech; autism; NSOME; oral motor; pronunciation.*

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Introduction

The patterns of a phenomenon might define the entity. If one understands the patterns of the maze, he can find his way there. Patterns of colors on a dress will hold its characters and soul. Understanding the expressive patterns of a developmental syndrome enables treating it with success. It is true for treating Childhood Apraxia of speech (CAS) as well. CAS as a motor-speech disorder involves difficulties in sounds production for speech purposes. The difficulties can be demonstrated in patterns that would be specific to CAS. These patterns can distinguish one phenomenon from another. The purpose of this article is to demonstrate typical versus CAS pathological speech patterns in Hebrew and analyze their consequences on speech therapy.

Typical speech patterns

How do we recognize and define the abnormal or pathological condition? Probably, by first understanding the typical range of the phenomenon. Whatever will not be within that range and relates to the phenomenon, will be different and require special care. The "normal" range is the area where most of the population will be found. For example, the IQ score. The median score will be 100 points by definition. The normal range was set to two standard deviations above and under the median score, hence will include 95% of the population. The 2.5% tails above and under the normal range are different according to the test. Therefore, in order to study and define the pathological speech patterns we should first discuss the typical speech pattern range.

The vowel is the dominant sound in the word and the first sound to be acquired (Vowel, 2013). The order of consonants acquisition in Hebrew (see figure 1) teaches us of the level of difficulty in pronunciation of each consonant (Lavie, 1978).

Figure 1 – Consonant acquisition in Hebrew

3;0	f, p , b , m , n , j
3;6	l , k , x
4;0	r , g , t
5;0	d
6;0	ts , z , s , sh , h , v

Fig 1 - The age at which 90% of the children have good control over the consonant
Source: authors'own contribution

The consonants are divided into different overlapping groups based on: place of articulation, voice and manner (Consonant, 2013). Analyzing the consonant acquisition table and consonant features together brings up interesting conclusions. First, vowels do not appear in the sounds acquisition chart, probably since they are considered to be the first sounds the child acquires, hence no need to examine them (Donegan, 2013). It is interesting that vowels are not in the chart, since in some pathological cases we might not have control over a vowel while having good control over some of the consonants (Burlea et al., 2010).

The bilabial group (m, b, p) appears to be mastered first. That might be attributed to the high visual component in learning these consonants. The /f/ consonant is also placed in the first group and that can be attributed to the early acquirement of the blowing skill, since a major component in producing /f/ is blowing. Consonant /n/ is the first alveolar consonant to appear and it might be attributed to its nasality. The /m/ consonant, the second nasal consonant which appears also in that first group, might be the reason for the early acquisition of /n/, due its nasality. Consonant /j/, that represents the sound /ya/ in Hebrew, appears also in the first group. This consonant can be considered a diphthong. Since vowels are the first to be learnt, finding consonant /j/ on the first group can be expected.

The second group of consonants consists of 3 consonants /l/, /k/ and /x/ (the sound /cha/ in Hebrew). /l/ is the second alveolar consonant to come and probably follows the /n/ consonant. They are both non plosive while the other alveolar consonants to come are plosive. /k/ is a non-voiced, velar and first tongue related plosive consonant to come. It is accompanied by the /x/ consonant, which is a non-voiced, uvular consonant. Even though /x/ is a fricative consonant, the similarity in place and voice can explain the similar time of acquisition.

The third group of consonants consists of 3 consonants: /r/,/g/ and /t/. The fourth group consists of only the /d/ consonant. Consonant /r/ is very similar in place to /x/, but since the manner of vibration is more difficult to master then friction, /x/ comes before /r/. Through groups 2^{nd} to 4^{th} we can identify two couples: /k/, /g/ and /t/, /d/. The difference between the sounds in each group is only the voice aspect, while the non-voiced consonants come before the voiced consonants. It is true also for the /x/, /r/ coupling. The probable explanation is the complexity of planning and executing a voiced consonant in comparison to a non-voiced one.

The last group of consonants consists of fricative consonants, four of which are voiceless (ts, s, sh, h) and two are voiced (z, v). The fricatives are the most difficult consonants to pronounce accurately, probably due to the high complexity of articulation in comparison to the other consonants.

That was the typical pattern of consonants acquisition in Hebrew and the logic behind it. The typical reasoning is not kept, and the speech patterns are different in the non-typical speech development. High variance of speech patterns can be found among children diagnosed with CAS. The next sections will deal with CAS speech characteristics and patterns as presented in the literature.

What is CAS?

The updated definition of CAS according to the American Speech-Language-Hearing Association (ASHA) 2007 is: "... a neurological childhood (pediatric) speech sound disorder in which the precision and consistency of movements underlying speech are impaired in the absence of neuromuscular deficits (e.g., abnormal reflexes, abnormal tone) …".

Shriberg estimated the CAS prevalence as 1-2/1000 based on the proportion of children referred to one university clinic (Shriberg, 1997). Yoss reported a prevalence of 1% using his criteria for suspected CAS (Yoss, 1975), while Morely reported 1.3% of CAS (Morley, 1975). Mckinon calculated the prevalence of stuttering, voice and Speech Sound Disorder (SSD) among 10425 children in 36 primary schools in Sydney, Australia (McKinnon et al., 2007). The SSD includes CAS and Articulation disorder (characterized by substitution, omission or distortion of speech sounds). Although tested separately, the CAS and articulation score combined post-hoc under one SSD score due to difficulties in differential diagnosis. The SSD prevalence was 1.06%. 13 children were found with CAS (0.12%). This study was taken in a regular primary school, so it did not include the children in the special education schools of the same cross-sectional sample. Hence the prevalence of the SSD should be higher. Davis suggested few overall features of the CAS population such as: higher incidence in males, normal intelligence, normal comprehension, delayed language development, normal hearing, and general motor clumsiness (Davis, 2011). Newmeyer et al found sensory regulation deficiency in children diagnosed with CAS compared with regular development control group (Newmeyer et al., 2009).

CAS speech characteristics

Levelt, Roelofs & Meyer distinguished between three different stages of speech disorders and their pathologies: 1) impairments of lexical access to the word form (classic anomia), 2) phonological encoding (post lexical phonological disorder), and 3) phonetic encoding (apraxia of speech). CAS causes deficits in the production of consonants, vowels and the formation of words (Levelt, et al., 1999).

Shriberg et al. identified segmental and supra-segmental characteristics of CAS. The segmental characteristics include: (a) an articulatory struggle (groping) particularly on word onsets, (b) trans positional (metathetic) substitution errors reflecting sequencing constraints on adjacent sounds, (c) marked inconsistencies on repeated tokens of the same word type, (d) proportionally increased sound and syllable deletions relative to overall severity of involvement and (e) proportionally increased vowel/diphthong errors relative to overall severity of involvement. The supra-segmental characteristics include: (a) inconsistent realization of stress (i.e. prominence on syllables or words), (b) inconsistent realization of temporal constraints on both speech and pause events and (c) inconsistent oral-nasal gestures underlying the percept of nasopharyngeal resonance (Shriberg et al., 2003). Shriberg, Lohmeier, Strand & Jakielski (2012) reported of new elements in CAS basic characteristics such as encoding, memory and transcoding deficits. Davis, Jakielski & Marquardt (1998) searched the literature for CAS criteria in order to examine 5 patients and mentioned speech and non-speech characteristics.

CAS diagnosis

CAS lacks a formal and reliable diagnosis. Research work has been done in the last 25 years but still there is no consensus or gold standard that will enable a formal diagnosis. Shriberg, Paul, Black & Van Santen (2011) mention an estimate of 80-90% false positive CAS diagnosis based on published and unpublished sources, which reflects the lack of consensus on the inclusionary and exclusionary criteria for this disorder. Forrest brings the Speech Language Pathologists (SLP) definition or perception of CAS (Forrest, 2003). 75 SLPs participated in the study and suggest 50 different items for CAS diagnosis. The most common 6 items appeared in 51.5% of the responses and included inconsistent production, general oral-motor difficulties, groping, inability to imitate sounds, increasing difficulty with increased utterance length, and poor sequencing of sounds (Lupu et al., 2016; Lupu, et al., 2016, Lupu et al., 2015). A similar research performed in Sweden came with more consensuses about the main features of CAS (Malmenholt et al., 2012). The survey included 25 questions while 127 SLPs responded. 85% of the participants suggested inconsistent errors as the core feature of the disorder, 82% noticed difficulties with automaticity and 71% difficulties with sequence maintenance.

A new diagnostic tool for CAS called the Dynamic Evaluation of Motor Speech Skill (DEMSS) was published recently (Strand et al., 2013). The authors used a hierarchical agglomerative cluster analysis in order to identify groups of children with similar features of speech patterns. The DEMSS was able to identify the children diagnosed with CAS but not all of them.

The purpose of this study was to explore the unique speech patterns of the children diagnosed with CAS in order to improve the decision-making process of the clinicians working with that population.

Method

A retrospective study was conducted analyzing 277 entry evaluations of children diagnosed with CAS or suspected CAS. The participants contacted an early age clinic for speech evaluation on their own will. The data was collected over the period 2006-2013 of children evaluated at the early age clinic in Israel. A set of variables based on the VML method assessment was established for the retrospective data collection (Vashdi, 2013; Vashdi, 2014). Each evaluation was examined thoroughly by a few examiners. Inter-rater reliability was tested over 20 cases and found to have 81% agreement. The data was extracted according to a detailed index. Each variable had a scale of 3-5 points score with a specific definition of each stage for scoring. Evaluations inclusion criteria were: 1. Suspected CAS or CAS diagnosis. 2. Extracting at least 80% of needed data. Data that wasn't clear enough to fit the variables criteria wasn't used. 3. Evaluations in the Hebrew language only. Evaluations were examined regardless of any other conditions to ensure non-selective procedure.

Subjects

277 entry participants were examined. Gender distribution - 76.6% boys, 23.4% girls. Average age was 4;11 years old. Age range was 1;7 – 19 years old. All subjects came with a previous diagnosis by a certified examiner (SLP or Neurologist). 13.7% were diagnosed with CAS, the rest of them (86.3%) were diagnosed with suspected CAS. 61.15% of them were diagnosed with Autism Spectrum Disorder (ASD) as well.

When retrospectively testing the data for each child, considering the guidelines and characteristics for CAS, all the children fit the CAS definition (American Speech-Language-Hearing Association, 2007; Forrest, 2003; Malmenholt, 2012< Shriberg et al., 2003). The average score percentage of single sound production (SSP) was 25.6%. On the words level, 74.7% could not pronounce words of any structure, 8.9% could only pronounce CVCV word structure, 4.4% could pronounce CVCV +CVC word structures, 2.2% could pronounce CVCV +CVC + CVCVC word structures and 8.7% could pronounce more complex word structure accurately based on the mastered SSP.

CAS speech Patterns

The following correlations and variables were calculated in order to establish the CAS speech patterns: Blowing and SSP correlation, Oral motor and SSP correlation, SSP ladder (order of sounds by relative strength), Sounds ladder within consonant group, Consonant groups ladder, Vowel groups ladder, WIV and the glottal consonant.

In addition, we performed a consonants exploratory factor in order to find "resonating" consonants and consonant groups. Including all the participants in this analysis might not serve the purpose of primary question since, in cases of having most of the sounds or not having them at all (very high scores and very low scores), the unique relationship between consonant groups will not be highlighted. Therefore, we performed the factor analysis procedures for two groups – all the participants (SSP) and for participants with SSP score between 15 % and 80% (SSP2).

Results

High correlation between the blowing skill score and SSP score was found (r= 0.61), as well as between the Oral Motor skill score and SSP score (r=0.62).

Table 1 – SSP rank

rank	sound	score	rank	sound	score	rank	sound	score	rank	sound	score
1	A	590*	29	mu	251	57	ku	201	85	fa	144
2	Ba	501*	30	ff	249	58	go	198	86	fu	144
3	O	456	31	meh	247	59	gu	194	87	fi	144
4	I	456	32	ne	247	60	gg	194	88	su	143
5	Ma	434	33	pu	246	61	je	187	89	vu	142
6	U	397	34	di	243	62	ji	175	90	che	141
7	E	385**	35	la	241	63	ll	174	91	shi	140
8	Pa	369	36	ni	239	64	jo	173	92	chu	139
9	Mm	355	37	ss	232	65	tsts	172	93	vo	139
10	Bo	341	38	do	230	66	leh	171	94	so	138

11	Da	332	39	ja	229	67	cha	171	95	si	138
12	Na	323	40	dd	229	68	ju	170	96	sho	132
13	Bu	312	41	to	229	69	li	170	97	shu	130
14	Ta	308	42	tt	226	70	vv	168	98	tsa	129
15	Bi	306	43	te	225	71	ze	162	99	tse	128
16	Be	289	44	kk	224	72	fo	157	100	zi	124
17	Pi	284	45	ti	223	73	va	157	101	zu	122
18	Po	283	46	no	222	74	sa	156	102	tsi	121
19	Shsh	279	47	nu	220	75	sha	154	103	za	120
20	Bb	278	48	lo	220	76	lu	152	104	zo	119
21	Mi	276	49	de	220	77	chi	151	105	tso	115
22	Ka	276	50	gi	220	78	fe	151	106	tsu	115
23	Ga	271	51	chch	220	79	cho	149	107	rr	100
24	Pp	267	52	du	217	80	se	149	108	ra	94
25	Ke	261	53	ge	215	81	vi	147	109	ro	87
26	Pe	258	54	ko	215	82	she	146	110	ri	87
27	Mo	257	55	ki	212	83	zz	146	111	re	84
28	Nn	254	56	tu	209	84	ve	145	112	ru	83

Source: authors'own contribution

(*) significantly different from one score below (<0.05),
(**) significantly different from two scores below (<0.05)

SSP scores within consonant groups found the first ranked sound in the group to be significantly distinctive from the second ranked sound in all groups. Table 4 shows the rank of the consonant groups. Differences between consonant groups and comparison to the regular development are discussed further in the discussion section.

Table 2 – Within consonants group SSP ladder

Rank	Group	percentage	Rank	Group	percentage	Rank	Group	percentage
1	Glottal	54.97*	8	k	27.86	14	x	19.47
2	b	40.65	9	g	25.91	15	s	19.17
3	m	36.50	10	l	22.62	16	v	18.01
4	p	34.24	11	Y (j)	22.48	17	z	15.90
5	n	30.18	12	F	19.84	18	ts	15.64
6	d	29.50	13	Sh	19.68	19	r	10.73
7	t	28.48						

Source: authors'own contribution

(*) significantly different from one score below (<0.05)

The inclusive vowel groups' ladder is presented in Table 3. The strongest vowel group is Va followed by 3 similar groups (Vo, Vi, Ve). The weakest vowel group was Vu.

Table 3 – Inclusive Vowel-form groups' ladder

Vowel group	Va	Vo	Vi	Ve	Vu
Percentage	31.66*	24.45	24.42	24.14*	21.49

Source: authors'own contribution

(*) significantly different from one score below (<0.05)

Consonants Exploratory factor analysis

Factor analysis procedure for all the subjects, demonstrated two consonant groups – fricatives (ch, r, sh, s, ts, z, f, v) and the rest (WIV, y, b, m, p, n, l, t, d, k, g). Reducing the subjects group to subjects who had SSP score of 15%-80% demonstrated 5 groups (Table 4).

Table 4 – Rotated factor analysis

Group	**Components**
1	sh, s, ts, z, f, v
2	y, n, l, t, d
3	WIV, b, m, p, n
4	k, g, ch
5	n, l, r, f, v

Source: authors'own contribution

Discussion

This article explored the speech patterns among children diagnosed with CAS. The large number of cases and the use of SSP in analysis of patterns enable us to learn much more about the speech patterns and to get implicated in treatment use. The next section will discuss the theoretical and functional implications of the findings.

Preverbal skills were found correlated with SSP. The literature does not support the use of NSOME in the speech treatment (Lof, 2007). In this research we found that there is high correlation between the NSOME skill level and the ability to pronounce the SSP. We cannot draw any conclusions regarding directional influences between speech production and NSOME practice among children with CAS; however, these findings suggest that there might be an influence. Since the NSOME skill is acquired in typical development before the speech skill, it makes sense to consider the NSOME to be a prerequisite skill for speech appearance, this is the common perception among speech therapists.

In Table 1, all the SSP are ranked according to the relevant strength from the strongest to the weakest. The ranking represents the overall tendency and not necessarily the developmental picture in any single CAS case. However, we can learn about very interesting phenomena discovered through the ranking:

1. The 5 WIV in Hebrew appear within the first 7 sounds. WIV are considered to emerge before the consonants in regular development and that is the case in the CAS sounds development as well.
2. The first consonants to appear are the bilabials (first 5 syllables which are not WIV). Lavie describes 6 consonants In typical development within the first consonant group (f, p, b, m, n, j) (Lavie, 1978). For the CAS group, the bilabial consonants are the strongest probably due to clarity of oral movements.
3. Surprisingly, the coda form (final consonant) of the /sh/ consonant is ranked 19 in the SSP ranking. That can be explained by the high correlation between the blowing skill, which appears earlier, and the consonant /sh/.
4. No difference in the vocal aspect of consonants was found, suggesting that in CAS there is no preference for voiced or non-voiced consonants.
5. The first 6 fricative consonants in the ranking were in coda form (/sh/ ranked 19, /f/ ranked 30, /s/ ranked 37, /ch/ ranked 51, /ts/ ranked 65 and /v/ ranked 70). These findings suggest that adding a vowel to a fricative consonant is hard for the child with CAS. The reason might be timing. Since the fricative consonant is elongated without a specific temporal ending point, in comparison to a plosive consonant, it is hard for the child to time the entrance of the vowel (Nittrouer et al., 1989).
6. The first two sounds (ah & ba) together form the word /Aba/ which means /dad/ in Hebrew. Sounds ranked 3 and 4 (i and ma) together form the word /ima/ which means /mum/ in Hebrew. These words have the strongest emotional meaning for the Hebrew speaking child, hence the biggest motivation for pronunciation and using in interaction. We can assume that the ranking of these sounds is influenced culturally by the Hebrew language.

7. The sounds ranked 77 – 112 (last) were non-plosive and mostly fricatives (72% of all fricatives sounds). That represents the difficulty in pronouncing fricative syllables in comparison to rest of consonants.

Table 3 demonstrates the intra-consonant syllable ranking. Analyzing patterns within consonant groups discovers intra-consonant patterns and suggestions for intervention:

The syllable /ba/ was found to be the strongest within the /B/ group, which is correlated with the strength of the vowel /a/. Surprisingly /bu/ is ranked 3rd although the vowel /u/ was found to be the weakest among the vowel groups.

The coda form of the fricatives (/ch/, /f/, /sh/, /s/, /ts/, /v/, /z/) was found the strongest as in all the fricatives but /z/ (ranked 2nd). It is easier to pronounce the fricative consonant without a vowel for few reasons; firstly, fricative sounds relay heavily on blowing and share similar properties and secondly, the fricative consonant is non-plosive and elongated. It is difficult for a child with CAS to add a vowel to a fricative consonant due to timing.

The nasal consonants (/m/,/n/) show similar patterns between them, which are different to the other consonants' patterns. The vowel /a/ was ranked first as with most of the other consonants, however, the coda form (ranked 2nd for both) was stronger in comparison at the plosive consonants, and more alike the fricatives. That suggests similarity between the nasal consonants and the fricatives.

The syllable /ke/ appears 2nd in the /K/ ranking due to language influence (/ken/ means /yes/ in Hebrew which is a highly common word). At the /G/ consonant group the syllable /gi/ ranked 2nd, probably due to similarity between the tongue's height of the vowel and consonant (high tongue at /i/ and at /g/ production). This phenomenon can be used in treatment while choosing the syllable /gi/ as a preferred junction point for achieving the consonant /g/ or the vowel /i/.

WIV - The vowel patterns with a glottal consonant are similar to the general vowel patterns except the vowel /e/. As WIV it was ranked last, probably due to the mid position of its control parameters. The tongue is placed in the middle (vertical and horizontal planes), jaw opening is in the middle and there are no extreme movements of the lips or any other articulator. That mid-position feature is not easy for a child with CAS to understand, since the boundaries of the movements are not obvious.

The consonants ladder - most of the speech developmental charts attribute to the consonant level. Table 2 summarizes the relative strength of the consonants. We treated the word-initial vowel as the glottal plosive consonant, and it came first in the ladder by far. The first group in Lavie's research includes the consonants /f/,/m/,/b/,/p/,/j/,/n/ (Lavie, 1978). In our study, /m/,/b/,/p/ and /n/ were found in the first level but /f/ and /j/ were ranked 11 and 10 respectively, though close together. It was easier for the children to acquire first the plosive consonants /t/, /d/,/k/,/g/ then the /f/ and /j/. Examining the consonants control broad picture shows clearly that the plosive consonants come first and only then the non-plosive (most of them fricatives). It is easier for the children diagnosed with CAS to acquire the plosive consonants since the beginning and end of the movement is clear, which is not the case for the non-plosive consonants

The inclusive vowels ladder found vowel /a/ group as the strongest and vowel /u/ as the weakest. These findings can serve clinicians in choosing targets for practice and can explain clinical phenomena.

The purpose of the factor analysis process was to explore relationships between consonant groups, in order to explain consonants development. Moreover, it can help in speech evaluation and targeting objectives in CAS treatment. Analyzing the whole participants group (n=277) yielded 2 groups (SPP1 score). There is a clear distinction between the fricatives group and the rest of syllables. The fricatives are more difficult to obtain for CAS population as for typical developing children. The SSP2 anaylsis yield 5 groups which resonate with the typical consonants development. In group 1 we can find all the fricatives (sh, s, ts, z, f, v) but /ch/ (group 4 with k, g). This group was kept almost as in the first SPP1 group. Group 2 consisted mostly of tongue's front consonants (y, n, l, t, d). It emphasizes the importance of the tongue position rather than other elements such as manner of articulation or voice. In group 3 we can find the bi-labial consonants (b, p, m), n, and the WIV. Bi-labial consonants and WIV are known to be the strongest sounds. The consonant /n/ is probably relates to this group due to nasality factor and affinity to /m/. Group 4 consisted of 3 back of the mouth sounds (k, g, ch). It is a small group with a very specific common factor – place of articulation – just like group 2. Group 5 on the other hand has a different relationship between the consonants. 4 of them appear in another group while the consonant /r/ joining them. It seems like the common feature is difficulty to pronounce these sounds. In some cases, we would find a difficulty to produce all of them.

Limitations

Since this research is using retrospective data, we do not have control over all the variables as in prospective research. Some variables could not be found in all cases, which excluded these cases from the research. Some of the data needed to be speculated from the texts causing possible errors in data collection. However, the inter-rater tests showed good agreement. The CAS definition is not clear and precise for all children since there is no acceptable gold standard based diagnostic tool. We should consider all these limitations when concluding towards clinical implementations and theoretical hypothesizes.

Summary

This research is unique in size and data regarding the CAS population research. Even though retrospective, it shed light on the population's speech patterns like no other research work before, since it analyzed data at the single syllable level. The patterns revealed in this research support some of the finding regarding typical speech development through unique aspects and show other sides and different reasoning of typical speech production. We should consider these findings in planning speech treatment and evaluation.

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