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Can the Accuracy of Clusters Determine their Developmental Stage in Children Using the Measure for Cluster Proximity (MCP)?

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Abstract: Children find it difficult to produce consonant clusters during their speech development. Cluster accuracy is widely measured by the proportion of clusters correct (PClC). However, this measure does not quantitatively identify developmental stages in clusters, that is, reduction, vowel epenthesis, or cluster production. The recently proposed measure for cluster proximity (MCP) achieves this by taking into account cluster member accuracy as well. The present study examines whether the aforementioned two measures, PClC and MCP, are correlated for word-final two-member clusters in child English speech. If they are correlated, cluster accuracy can then determine cluster developmental stages. Using thirty-one children's speech samples, each sample comprising several word-final clusters at different developmental stages, it is found that MCP and PClC are strongly and significantly correlated across the children's speech samples when classes of clusters or several different clusters are considered cumulatively.

Keywords: Consonant clusters, accuracy, development, MCP, stages, child speech.

1 Introduction

English is comprised of consonant clusters which dominate the word-final position and occupy the word-initial position in one third of monosyllabic words [1]. In their speech development, children normally acquire consonant clusters after singleton consonants or vowels [2]. Although consonant clusters are produced correctly as early as two years of age [3], they are normally acquired by about age 5 [4, 5, 6]. However, about 5% of six-year-olds are diagnosed with a speech sound disorder (SSD) [7] which delays cluster acquisition. There are four main stages in the development of two-member consonant clusters: omission of both members, reduction to one member, vowel epenthesis between the two members, and two-members, with member accuracy distinguishing productions within a stage [4, 8, 9]. Also, there is a stage where a consonant is added between the two members for children in typical and atypical development [10].

Besides a qualitative evaluation, it is important to quantitatively evaluate clusters in order to assess children's developmental level. Until recently, there were two

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measures applied in the literature: the percentage of consonants correct (PCC) [11, 12], and the percentage of clusters correct (PClC) [13, 14]. The former measure addresses accuracy of cluster members, while the later measure addresses whole cluster accuracy. However, none of these measures distinguishes developmental stages of clusters. The recently proposed measure for cluster proximity (MCP) [15] achieves this. In this measure, complete omission is scored 0 points, reduction is scored 1 or 2 points depending on whether the produced consonant is accurate or not, vowel epenthesis is scored 1 point in addition to the points for the two consonants, and two-member production is scored 4 points in addition to the points for the two consonants. Then MCP is obtained by dividing the cluster production's points by 8, which is the score for an accurate cluster [15]. The comparison between MCP and PClC at different developmental stages is shown in Table 1.

Table 1. Comparison of MCP and PClC in cluster developmental stages

Process	**Om**	**Rd**		**VE**			**2M**		
production/ measure	DD	SD/ DS	CD/ DC	SVS	SVC/ CVS	CVC	SS	SC/ CS	CC
MCP (%)	0	12.5	25	37.5	50	62.5	75	87.5	100
PClC (%)	0	0	0	0	0	0	0	0	100

N.B. Om: omission, Rd: reduction, VE: vowel epenthesis, 2M: 2-member production; D: deletion, S: substitution, C: correct, V: vowel

It is observed that, on the one hand, PClC only distinguishes accurate from inaccurate clusters by assigning a score of 100% and 0% respectively. However, on the other hand, MCP distinguishes all the developmental stages from each other by assigning a score of 0% to omitted clusters (both members deleted, DD) and adding a score of 12.5% for successively improved performance, until 100%, the score of an accurately produced cluster (both members correct, CC).

It is apparent, therefore, that MCP and PClC generally differ when computing productions of individual clusters. When, however, the two measures are applied to several clusters across children, they may be correlated. It should be noted that MCP has been recently found to be strongly and significantly correlated to cluster member accuracy, PCC, for word-initial clusters [16].

In the present article, it will be examined whether MCP and PClC are correlated for word-final two-member clusters and whether the correlation is strong and statistically significant. This will be done here by considering thirty-one children's speech samples, each sample containing several word-final clusters.

2 Method

The data employed comprise thirty-one English speech samples from eighteen children. In order to have a sufficient amount of data for clusters in all developmental stages, speech samples from both normally developing children and children with speech-sound disorders (SSDs) are used. Twenty-five of the speech samples come from articulation/phonology tests that were given to children with SSDs, by showing the children pictures representing the words to be produced by them. Six of the speech samples come from the running speech of two normally developing children at three different ages in relatively early speech development.

The twenty-five speech samples come from sixteen children with SSDs. Their age, test of articulation/phonology taken and words in the test with word-final clusters, are given below. When more than age is shown for a child, the speech samples were from tests taken by the child before and after speech therapy.

Jarrod (7;00) [17]; Diagnostic Evaluation of Articulation and Phonology (DEAP) [18] and Morrisette supplemental word list [19]: *Alex, beans, biscuits, box, drink, elephant, front, girls, gloves, island, orange, present, shrink, stripes, swapped, think, twelve, twins*.

Lori (7;6) and **Ryan (6;6)** [20]; Arizona Articulation Proficiency Scale [21]: *books, bird, carrots, cold, fork, horse, jumping, nest, steps*.

Andrew (5;6), **Dillon (7;6)** [20] and **Timmy (5;5)** [22], Hodson Assessment of Phonological Patterns (HAPP-3) [22]: *boats, clouds, crayons, fork, horse, ice cubes, jumping, mask, music box*.

Annie (3;1, 4;4), **Brad (4;11, 5;7), Kirk (K) (14;0, 14;3)** [23] and **female** (4;1, 4;4) [24]; Hodson Assessment of Phonological Patterns (HAPP-2) [23]: *boats, crayons, fork, horse, ice cubes, jump rope, mask, music box*.

Alan (5;11, 7;5), **Barry (8;9, 8;10)**, **Bobby (4;5, 4;11)**, **Danny (5;6, 6;5)**, **Jerry (5;7, 6;3)**, and **Tim (6;1)** [25]; Hodson Assessment of Phonological Patterns (HAPP-1) [25]: *crayons, fork, horse, ice cubes, jump rope, mask, music box.*

The two children in typical speech development, their age, and target words with word-final clusters in running speech are:

Amahl (2;6) [26]: *called, different, elephant, else, fact, felt, footprint, found, gonk, ground, hold, kind, Lapland, last, left, lift, lost, milk, opened, rubber band, shelf, six, soft, trunk*.

Amahl (2;7) [26]: *beads, bend, bent, bookshelf, box, can't, climbed, clothes, dent, desk, different, drink, Elastoplast, elf, fact, find, footprint, fox, gonk, ink, just, lift, malt, meant, milk, once, pink, pleased, point, post, reins, rubber band, scales, sneezed, soft, sponge, tent, thank you, think, touched, twist, vest, want, won't.*

Amahl (2;8) [26]: *ask, blank, cans, cats, cleaned, clothes, cracked, desk, difficult, drink, drunk, field, flex, fox, front, hand, jump, let's, lunch, old, paint, pens, pick, poked, post, salt, scales, sink, soft, squeezed, stamp, supposed, thank you, think, twist, used, want, won't.*

Maria Sofia (2;7) (present study): *behind, boots, box, breakfast, bricks, chocolates, cold, dance, don't, drink, else, find, finished, fits, found, help, hold, last, legs, let's, lips, lost, milk, missed, mountains, moved, pavement, restaurant, steps, suds, want, won't.*

Maria Sofia (3;0) (present study): *accident, animals, Athens, balance, balloons, belt, bend, blocks, boats, boots, box, called, child, chips, clothes, cold, don't, drink, eggs, elephant, else, end, find, found, fox, grapes, hand, hold, jokes, left, legs, lentils, let's, looks, lunch, milk, myself, ones, orange, pink, restaurant, round, sand, seeds, self, serpent, skipped, socks, soft, spoiled, sticks, stopped, that's, things, toast, want, washed, went, wind.*

Maria Sofia (3;5) (present study): *Athens, balloons, balls, behind, bits, blocks, boots, box, breakfast, breaks, bricks, change, choked, clips, clothes, cold, connect, difficult, dots, dressed, drink, dust, else, fault, find, fix, found, gift, hand, help, hold, jump, left, legs, lets, licked, licks, lift, liked, likes, lost, lunch, milk, mind, nest, nostrils, old, ones, oops, orange, pegs, perhaps, pink, placed, reached, rest, restaurant, round, runs, scratched, six, soft, someone's, stamp, tent, thank, that's, think, want, wolf, yourself.*

3 Results and Discussion

I. Each child

Each child's productions of word-final clusters are presented in Tables 2-11 below. The first column lists targeted clusters, the second column shows productions, the third and fourth columns give the computed PClC and MCP, and the last row provides the mean PClC and MCP for all clusters. When a table includes a child's productions at an older age, after speech therapy, or another child's productions, the table extends its columns in a similar manner.

Table 2 gives the results for Jarrod (7;0). It is seen that the largest deviation between MCP and PCC is 0.458, when cluster *nt* is produced both as one correct member, *n*, and as a two-member cluster with the glottal stop ʔ substituting *t*. The

smallest deviation between MCP and PClC is 0.0, when clusters *ps*, *vz*, and *lv* are omitted.

Table 2. Word-final cluster PClC and MCP for Jarrod (7;0).

CC	Ja 7;0	PClC	MCP
pt	p	0	0.25
ps	∅	0	0
ts	ʔ	0	0.125
ks	ʔh,h	0	0.438
vz	∅	0	0
nt	nʔ,2n	0	0.458
nd	n	0	0.25
ndʒ	n	0	0.25
ŋk	ʔk,ŋk,ŋ	0.333	0.708
nz	2n	0	0.25
lv	∅	0	0
lz	2l	0	0.25
	M	**0.028**	**0.248**

In Table 3 the results for Lori (7;6) and Ryan (6;6) are shown. While the average MCP over all clusters is higher than 90% representing complete acquisition of clusters for Lori, her corresponding PClC is below 70%. The largest difference MCP and PClC, 87.5%, for the production of *ps*, *ks* and *rs*. Ryan's mean cluster scores between MCP and PClC also differ by about 30%. The smallest difference between MCP and PClC is for his accurately produced clusters, *mp*, *rd*, and *rk*, with both measures assigning a score of 1.

Table 3. Word-final cluster PClC and MCP for Lori (7;6) and Ryan (6;6).

CC	L 7;6	PClC	MCP	R 6;6	PClC	MCP
ps	pθ	0	0.875	p	0	0.25
ts	ts	1	1	t	0	0.25
ks	kθ	0	0.875	kθ	0	0.875
st	st	1	1	t	0	0.25
mp	mp	1	1	mp	1	1
ld	ld	1	1	d	0	0.25
rd	rd	1	1	rd	1	1
rk	rk	1	1	rk	1	1
rs	rθ	0	0.875	rθ	0	0.875
	M	**0.667**	**0.958**	**M**	**0.333**	**0.639**

Table 4 gives the results for Andrew (5;6), Dillon (7;6), and Timmy (5;5). Andrew (5;6) produces only cluster *mp* correctly, reducing the rest and omitting *ts*

completely. As a result, PClC and MCP are the same only for complete acquisition and omission, but their mean values differ by less than 15%. Dillon (7;6) omits 5 of his clusters and reduces 4 of them, and only *mp* is reduced to a target, *m*. Thus, the mean PClC and MCP are very small, 0% and 6.9% respectively. Timmy (5;5) reduces all clusters, most of them to a target except those involving *k* and *s* that are substituted mostly by *ʔ*. As a result, PClC is smaller than MCP for all his productions but as much as 25%, resulting in a larger mean MCP than mean PClC by 19.4%.

Table 4. Word-final cluster PClC and MCP for Andrew (5;6), Dillon (7;6), and Timmy (5;5).

CC	Aw 5;6	PClC	MCP	Di 7;6	PClC	MCP	Ti 5;5	PClC	MCP
bz	b	0	0.25	ø	0	0	b	0	0.25
ts	ø	0	0	ø	0	0	t	0	0.25
dz	d	0	0.25	ø	0	0	d	0	0.25
ks	t	0	0.125	ø	0	0	ʔ	0	0.125
sk	t	0	0.125	t	0	0.125	ʔ	0	0.125
mp	mp	1	1	m	0	0.25	p	0	0.25
nz	n	0	0.25	ø	0	0	n	0	0.25
rk	t	0	0.125	t	0	0.125	ʊʔ	0	0.125
rs	t	0	0.125	t	0	0.125	ʊti	0	0.125
	M	**0.111**	**0.25**	**M**	**0.0**	**0.069**	**M**	**0.0**	**0.194**

In Table 5 the results for Annie (3;1, 4;4) and Brad (4;11, 5;7) are given. Before therapy, Annie (3;1) deletes all consonants in clusters, except in *mp* where she keeps *m*, resulting in negligible mean PClC and MCP. After therapy at age 4;4, however, she produces all clusters correctly except for *rhotic+C* which she reduces to target *C* as far as consonants are concerned. As a result, the mean of both measures shows cluster acquisition at or above the 75% level, their difference being only 6.3%. Before therapy, Brad (4;11), produces only one cluster correctly, *mp*, resulting in a PClC equal to 0 for all other clusters and an MCP equal to mostly 25%. Thus, the mean MCP is larger than PClC by 20.3%. After therapy, Brad's (5;7) productions are identical to Annie's (4;4), and, therefore, their PClC and MCP values are also identical.

In Table 6, the results for Kirk (14;0, 14;3) and a female (4;1, 4;4) child are shown. Before therapy, Kirk (14;0) reduces all clusters, completely omitting *ts*. Except for *nasal+stop*, all others are reduced to a target, resulting in a lower PClC than MCP, 0% and 18.8%, respectively. After therapy, Kirk (14;3) produces most clusters correctly, reduces *rhotic+C* to *C* and reverses member position in *sk*. As a result, the mean PClC and MCP are respectively below and above the 75% level. In contrast, to the other children with SSDs, the female (4;1, 4;4) child's MCP

decreases after therapy, while PClC remains the same. Before therapy, she omits *mp*, reduces *rs* to *s*, reverses member position in *sk*, but produces the remaining clusters correctly. Due to the latter production which is measured at 75% by MCP and 0% by PClC, the mean MCP shows the clusters overall acquired at 75% and the mean PClC at 62.5%. After therapy, however, the female child improves in producing *mp*, but deteriorates in producing *sk*, *rk* and *rs*, resulting on the one hand in the same mean PClC value and, on the other hand, in a lower MCP value, by about 5%. This happens because the therapy that was administered probably targeted the improvement of word-initial clusters and not word-final clusters.

Table 5. Word-final cluster PClC and MCP for Annie (3;1, 4;4) and Brad (4;11, 5;7).

CC	An 3;1	PClC	MCP	An 4;4	PClC	MCP	Br 4;11	PClC	MCP	Br 5;7	PClC	MCP
bz	ø	0	0	bz	1	1	b	0	0.25	bz	1	1
ts	ø	0	0	ts	1	1	t	0	0.25	ts	1	1
ks	ø	0	0	ks	1	1	s	0	0.25	ks	1	1
sk	ø	0	0	sk	1	1	s	0	0.25	sk	1	1
mp	m	0	0.25	mp	1	1	mp	1	1	mp	1	1
nz	ø	0	0	nz	1	1	n	0	0.25	nz	1	1
rk	ʊ	0	0	ʊk	0	0.25	əʔ	0	0.13	ʊk	0	0.25
rs	ø	0	0	ʊs	0	0.25	ʊs	0	0.25	ʊs	0	0.25
	M	**0.0**	**0.03**	**M**	**0.75**	**0.81**	**M**	**0.13**	**0.33**	**M**	**0.75**	**0.81**

Table 6. Word-final cluster PClC and MCP for Kirk (14;0, 14;3) and female (4;1, 4;4).

CC	K 14;0	PClC	MCP	K 14;3	PClC	MCP	f 4;1	PClC	MCP	f 4;4	PClC	MCP
bz	b	0	0.25	bz	1	1	bz	1	1	bz	1	1
ts	ø	0	0	ts	1	1	ts	1	1	ts	1	1
ks	s	0	0.25	ks	1	1	ks	1	1	ks	1	1
sk	s	0	0.25	ks	0	0	ks	0	0.75	k	0	0.25
mp	ʔ	0	0.13	mp	1	1	ø	0	0	mp	1	1
nz	m	0	0.13	nz	1	1	nz	1	1	nz	1	1
rk	ʊk	0	0.25	ʊk	0	0	rk	1	1	k	0	0.25
rs	ʊs	0	0.25	ʊs	0	0	s	0	0.25	t	0	0.13
	M	**0.0**	**0.19**	**M**	**0.63**	**0.78**	**M**	**0.63**	**0.75**	**M**	**0.63**	**0.70**

The results for Alan (5;11, 7;5) and Barry (8;9, 8;10) are shown in Table 7. Before therapy, Alan (5;11) completely omits clusters except for *nz* which he reduces to *n*. Consequently, both his PClC and MCP mean values are small, 0% and 3.6%. After therapy, Alan (7;5) produces correctly most of his clusters, resulting in similar much higher mean PCC and MCP values, 71.4% and 82.1%, respectively. For Barry (8;9, 8;10), however, MCP is much larger than PClC both before and after therapy due to the production of two-member clusters, with at least one

member incorrect. As a result, after therapy, MCP shows clusters acquired at 83.9%, while PClC shows them non-acquired at 57.1%.

Table 7. Word-final cluster PClC and MCP for Alan (5;11, 7;5) and Barry (8;9, 8;10).

CC	A 5;11	PClC	MCP	A 7;5	PClC	MCP	B 8;9	PClc	MCp	B 8;10	PClc	MCp
bz	ø	0	0	bz	1	1	bts	0	0.5	bz	1	1
ks	ø	0	0	ks	1	1	t	0	0.13	ks	1	1
sk	ø	0	0	sk	1	1	ts	0	0.75	ks	0	0.75
mp	ø	0	0	mp	1	1	mp	1	1	mp	1	1
nz	n	0	0.25	nts	0	0.5	nts	0	0.5	nz	1	1
rk	ø	0	0	ʊk	0	0.25	k	0	0.25	k	0	0.25
rs	ø	0	0	rs	1	1	ts	0	0.88	ts	0	0.88
	M	**0.0**	**0.04**	**M**	**0.71**	**0.82**	**M**	**0.14**	**0.57**	**M**	**0.57**	**0.84**

In Table 8, the results for Bobby (4;5, 4;11) and Danny (5;6, 6;5) are shown. Bobby's mean PClC is below the 75% level before and after therapy, while his mean MCP is above. On the other hand, Danny's mean values are both very low before therapy, while after therapy, MCP only MCP reaches the 75% level.

Table 8. Word-final cluster PClC and MCP for Bobby (4;5, 4;11) and Danny (5;6, 6;5).

CC	Bo 4;5	PClC	MCP	Bo 4;11	PClC	MCP	D 5;6	PClc	MCp	D 6;5	PClc	MCp
bz	bz	1	1	bz	1	1	b	0	0.25	bz	1	1
ks	ts	0	0.88	ks	1	1	k	0	0.25	ks	1	1
sk	sk	1	1	sk	1	1	t	0	0.13	ks	0	0.75
mp	mp	1	1	mp	1	1	m	0	0.25	mp	1	1
nz	nz	1	1	nz	1	1	m	0	0.13	nz	1	1
rk	ʊk	0	0.25	ʊk	0	0.25	ø	0	0	ʊk	0	0.25
rs	ʊs	0	0.25	ʊs	0	0.25	ø	0	0	ʊs	0	0.25
	M	**0.57**	**0.77**	**M**	**0.71**	**0.79**	**M**	**0.0**	**0.14**	**M**	**0.57**	**0.75**

The results for Jerry (5;7, 6;3) and Tim (6;1) are given in Table 9. Jerry's mean PClC and MCP values are below the 75% level before therapy and near the 75% level after therapy. Jerry (6;3) persists in producing *rhotic+C* as *vowel+C* but his mean MCP is above the 75%, while Tim (6;1) has problems with *stop+fricative* and *fricative+stop* with his mean MCP also near the 75% level but his mean PClC below at 57.1%.

Table 9. Word-final cluster PClC and MCP for Jerry (5;7, 6;3) and Tim (6;1).

CC	J 5;7	PClC	MCP	J 6;3	PClC	MCP	T 6;1	PClC	MCP
bz	bz	1	1	bz	1	1	bd	0	0.88
ks	ks	1	1	ks	1	1	t	0	0.13
sk	ks	0	0.75	sk	1	1	t	0	0.13
mp	mp	1	1	mp	1	1	mp	1	1

nz	n	0	0.25	nz	1	1	nz	1	1
rk	ʊk	0	0.25	ʊk	0	0.25	rk	1	1
rs	ʊs	0	0.25	ʊs	0	0.25	rs	1	1
	M	**0.43**	**0.64**	**M**	**0.71**	**0.79**	**M**	**0.57**	**0.73**

The results from two children's normally developing running speech are given in what follows. Because the speech is now running, there are several productions recorded for each word-final cluster since children generally produce the same words more than once and there are several words containing the same word-final cluster.

In Table 10, PClC and MCP are shown for Amahl at ages 2;6, 2;7, and 2;8. The mean PClC is lower than the mean MCP by 25%-30% at all three ages, although there are differences as much as 87.5% for individual clusters. It is observed that the mean MCP and PClC values remain about the same at the three ages, although there are substantial differences between them for individual clusters. This is because the child is at a plateau stage in speech development, known to generally last for several months, where there is basically no overall speech progress or very little. [27, 28, 29].

Table 10. Word-final cluster PClC and MCP for Amahl (2;6, 2;7, 2;8).

CC	Am 2;6	PClC	MCP	Am 2;7	PClC	MCP	Am 2;8	PClC	MCP
kt	t	0	0.25	kt	1	1	4kt	1	1
ʧt				t	0	0.25			
ts							2t	0	0.25
dz				d	0	0.25			
ks	kt	0	0.875	kt,2k	0	0.458	2k	0	0.25
ft	4pt,p,f	0	0.646	pt	0	0.875	pt	0	0.875
st	2t	0	0.25	5t	0	0.25	2t,p	0	0.208
zd				2d	0	0.25	bd,2d	0	0.458
sk				k	0	0.25	kt	0	0.75
θs				3d	0	0.125	d	0	0.125
mp							2mp	1	1
md				md	1	1			
nt	2t,n,Ø	0	0.188	7nt,5t,Ø	0.538	0.635	5nt	1	1
nd	7nd,4n	0.636	0.727	3nd	1	1	2nd	1	1
nʧ							nt	0	0.875
nʤ				nd	0	0.875			
ŋk	ŋk,k	0.5	0.625	6ŋk,2k,g	0.667	0.736	12ŋk,k	0.923	0.942
ns				t	0	0.125			
nz				n	0	0.25	n	0	0.25
lt	lt	1	1	lt	1	1	lt,l,Ø	0.333	0.417
ld	2ld	1	1				2ld	1	1
lk	lk, lik	0.5	0.813	lk	1	1			
lf	f	0	0.25	lef,f	0	0.438			
ls	lt	0	0.875						
lz				l	0	0.25	l	0	0.25
	M	**0.303**	**0.625**	**M**	**0.31**	**0.551**	**M**	**0.368**	**0.626**

Table 11. Word-final cluster PClC and MCP for Maria Sofia (2;7, 3;0, 3;5).

CC	MS 2;7	PClC	MCP	MS 3;0	PClC	MCP	MS 3;5	PClC	MCP
pt				2pt,p	0.667	0.75			
kt							ts,tt,tʃ	0	0.583
tʃt							tʃt, tʃ	0.5	0.625
ps	3ps,Ø	0.75	0.75	9ps	1	1	3ps,ts,ks	0.6	0.95
ts	9ts,st,8st	0.474	0.625	8ts	1	1	11ts	1	1
dz	ds	0	0.875	ts	0	0.75			
ks	ts,ʧ,t	0	0.375	17ts,2t 2s, Ø	0	0.710	11ts	0	0.875
gz	ts	0	0.75	6ts,dz	0	0.768	3ts,2dz,ds tʃ	0	0.696
ft				2ft,f,Ø	0.5	0.563	4ft	1	1
vd	zv	0	0.75						
st	3st,2ts 2s	0.429	0.607	3st,ts s,t	0.5	0.708	11st,ts,Ø	0.846	0.904
ʃt	ʃt,t	0.5	0.625	st	0	0.875			
θs				5s,Ø	0	0.208	ts,s	0	0.563
mp							2mp	1	1
nt	7nt,9t,3nʃ, 5Ø	0.28	0.405	14nt,5t 4n, 6Ø	0.483	0.560	24nt,11nt, 4Ø	0.6	0.675
nd	2nd,mt,nd	0.4	0.65	2nd,6nt 4n, t, Ø	0.143	0.598	13nd,2nt 8n, t, 2Ø	0.5	0.649
ntʃ				nts	0	0.5	4ntʃ	1	1
ndʒ				nts,tʃ ts, s	0	0.219	2ndʒ,nt ,nts	0.5	0.844
ŋk	2n,t	0	0.208	3nt,2t	0	0.575	11nt,4n 2Ø	0	0.625
ns	2ns,nts	0.667	0.875	ns,nts	0.5	0.813			
nz	ns,n	0	0.563	5ns,2nts ts,2s,Ø	0	0.580	9ns	0	0.875
lp	lp,2p	0.333	0.5				lp,6ɘp,Ø	0.125	0.313
lt				t,Ø	0	0.125	2t	0	0.25
ld	2ld,5d,l	0.25	0.438	let,d,t,2Ø	0	0.175	5d,2t,Ø	0	0.188
lk	5t	0.0	0.125	11t	0	0.125	lk,4lt,letɘt	0.143	0.732
lf				2f,s,2Ø	0	0.125	3ɘf,6f,l 2Ø	0	0.208
ls	s	0	0.25	lɔs	0	0.625	4s,Ø	0	0.2
lz				lz,ls,3s	0.2	0.45	3ɘs	0	0.125
	M	**0.240**	**0.551**	**M**	**0.217**	**0.557**	**M**	**0.340**	**0.647**

In Table 11, Maria Sofia's PClC and MCP cluster values are given at ages 2;7, 3;0, and 3;5. PClC and MCP substantially differ for most individual clusters, and the mean PClC and MCP differ by 30% to 35% at each age. Comparing their

corresponding values between ages, there is basically no change between 2;7 and 3;0, but an increase of about 10% in both PClC and MCP between ages 3;0 and 3;5. There is a plateau between ages 2;7 and 3;0, but some speech progress thereafter. This plateau coincides with the child's ages for a PCC plateau in the consonant singleton *theta* [29], as well as with the child's ages for a plateau in PCC and whole word phonological proximity (PWP) computed cumulatively for singleton-consonant words and cluster words [28].

II. MCP versus PClC across children

II.a: Mean MCP and PCLC over all clusters: The correlation between the mean MCP and PClC is examined now across children. The mean MCP and PClC values are presented in Table 12a for the children's thirty-one speech samples presented above. It is seen that the deviations between MCP and PClC vary between 3.1% and 35% and that there are several MCP values for PClC equal to 0%, as expected, because of the definition of the two measures as presented in Table 1. However, because MCP and PClC are averaged over all clusters per child, MCP does not deviate as strongly as it can for individual clusters (87.5%). In fact, the MCP deviations for 0% PClC are between 3.1% and 14.3%.

Table 12a,b,c. PClC and MCP across the children's thirty- one speech samples.

a) Mean		**b) *ks***		**c) nasal + C**	
PClC	**MCP**	**PClC**	**MCP**	**PClC**	**MCP**
2.8%	24.8%	0%	43.8%	6.7%	38.3%
66.7%	95.8%	0%	87.5%	100%	100%
33.3%	63.9%	0%	87.5%	50%	62.5%
11.1%	25%	0%	12.5%	100%	100%
0%	6.9%	0%	0%	0%	12.5%
0%	19.4%	0%	12.5%	0%	25%
0%	18.8%	0%	0%	0%	12.5%
62.5%	78.1%	100%	100%	100%	100%
0%	3.1%	0%	25%	50%	62.5%
75%	81.3%	100%	100%	100%	100%
12.5%	32.8%	0%	25%	0%	12.5%
75%	81.3%	100%	100%	100%	100%
62.5%	75%	100%	100%	50%	50%
62.5%	70.3%	100%	100%	100%	100%
0%	3.6%	0%	0%	0%	12.5%
71.4%	82.1%	100%	100%	50%	75%
57.1%	73.2%	0%	12.5%	50%	75%
14.3%	57.1%	100%	100%	100%	100%
57.1%	83.9%	0%	87.5%	100%	100%

57.1%	76.8%	100%	100%	100%	100%
71.4%	78.6%	0%	25%	0%	18.8%
0%	14.3%	100%	100%	100%	100%
57.1%	75%	100%	100%	50%	62.5%
42.9%	64.3%	100%	100%	100%	100%
71.4%	78.6%	0%	12.5%	100%	100%
30.3%	62.5%	0%	87.5%	37.9%	51.3%
31%	55.1%	0%	45.8%	45.8%	66%
36.8%	62.6%	0%	25%	65.4%	84.5%
24%	55.1%	0%	37.5%	26.9%	54%
21.7%	55.7%	0%	71%	16.1%	54.9%
34%	64.7%	0%	87.5%	51.4%	81%

In Figure 1, the data of Table 12a is presented graphically with PClC being the horizontal axis and MCP the vertical axis. It is seen that that there is a positive correlation between MCP and PClC whose best linear fit is given by the equation MCP = 0.931 PClC + 0.212, which is shown in the figure by the solid straight line. The correlation is very strong since the Pearson coefficient, r, is equal to 0.93, and it is also statistically significant since the probability F value is 4.02E-14 and the p-intercept value is 1.92E-07. Therefore, using this equation, the mean MCP over all clusters can be determined from the mean PClC with a coefficient of determination, r^2, equal to 0.865.

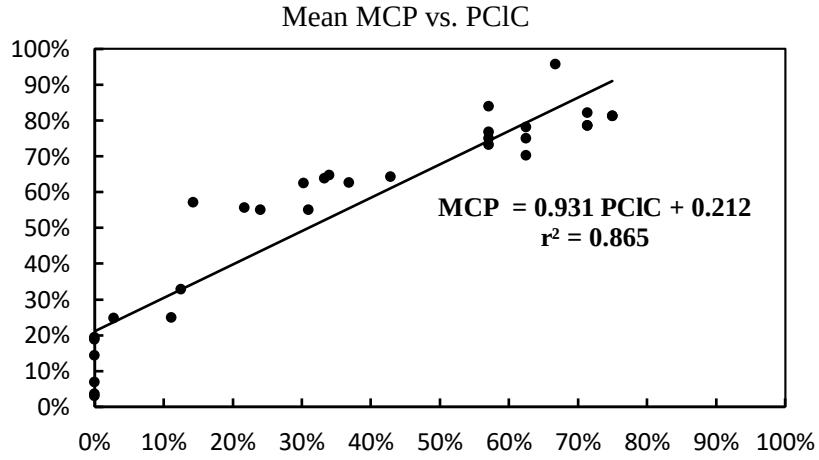

Fig. 1. Correlation between mean cluster MCP and PClC across children.

II.b: MCP and PCLC for individual clusters: When an individual cluster is considered, since one production is mostly included in the data per child, there is

expected to be large MCP variability for inaccurate productions (0% PClC) across the speech samples. This is a consequence of the definition of the MCP and PClC scales given in Table 1, resulting in an MCP variability from 0% to 87.5%. This is demonstrated here by considering the MCP and PClC values for word-final cluster *ks* across the thirty-one speech samples. These values are shown in Table 12b. It is seen there is no correlation between MCP and PClC due to the large MCP variability at 0% PClC.

II.c: MCP and PCLC for classes of clusters: When a class of clusters is considered for calculating MCP and PClC values, since the averaging is over a variable enough data, it is expected that there will be a positive correlation between MCP and PClC. Here, this is investigated by considering nasal+C clusters, that is, the MCP and PClC values are averaged over all word-final clusters whose first member is either *n* or *m* and the second member is any consonant. The resulting PClC and MCP values for the thirty-one speech samples considered in the present study are shown in Table 12c. It is seen that the largest deviation between the two measures is 38.8%.

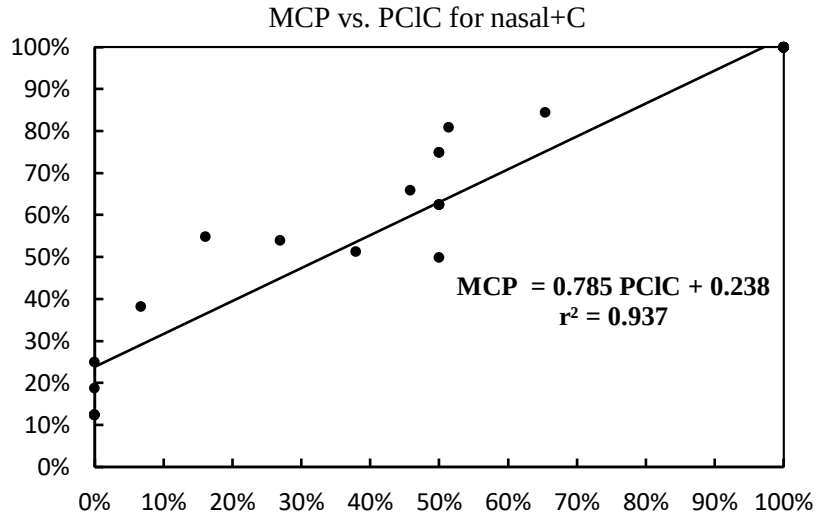

Fig. 2. Correlation between nasal+C MCP and PClC across children.

In Figure 2, the data of Table 12c is presented graphically with PClC being the horizontal axis and MCP the vertical axis. It is seen that that there is a positive correlation between MCP and PClC whose best linear fit is given by the equation MCP = 0.785 PClC + 0.238, which is shown in the figure by the solid straight line. The correlation is very strong since the Pearson coefficient, r, is equal to 0.968, and it is also statistically significant since the probability F value is 6.16E-

19 and the p-intercept value is 4.91E-10. Therefore, using this equation, the MCP for nasal+C clusters can be determined from their PClC with a coefficient of determination, r^2, equal to 0.937.

4 Conclusions

The correlation between the measure for cluster proximity (MCP) and the proportion of clusters correct (PClC) was examined for word-final clusters with the purpose of determining whether cluster accuracy can predict cluster developmental stage. It was found that averaging over classes of clusters or over several different clusters is sufficient for a strong positive and statistically significant correlation between the two measures. In both cases, Pearson's coefficient is higher than 0.92 and the probability F value much lower than 0.005, so that given PClC, MCP can be determined from a linear relationship between the two measures. These results can be used to quantitatively evaluate and assess children's acquisition of consonant clusters in development.

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