Oral Motor Complexity Score v.2: Advanced Kinematic Framework

Preface: About Advanced Kinematic Framework

This article represents a significant update to the **O**ral **M**otor **C**omplexity **S**core framework. While an earlier version was intentionally designed for accessibility by parents, caregivers, and non-specialists involved in supporting children with speech sound disorders, this **A**dvanced **K**inematic **F**ramework (v.2) is intended specifically for Speech-Language Pathologists, researchers, and developers of clinical AI tools.

This article introduces a "Hybrid Model" that retains the accessible consonant scoring of the original framework but replaces the simplified "Vowel Placement" section with a robust, biomechanically grounded logic known as the **Vowel Kinematics Score**. This update recognizes that vowels are not static acoustic targets but dynamic motor events requiring precise jaw grading, lingual dissociation, and trajectory management.

Clinical Utility: A Guiding Principle for Scaffolding

We acknowledge that the mathematical complexity of this updated scoring system (specifically the Context Multipliers) may be prohibitive for real-time calculation during therapy sessions. However, understanding these biomechanical variables provides a powerful framework for clinical decision-making.

For example, recognizing that a dynamic diphthong like /aɪ/ involves a rapid, cross-quadrant trajectory (Low-Back to High-Front)—making it generally more motorically demanding than a static vowel like /a/—offers a valuable lens for analysis. This kinematic perspective supports the clinician in scaffolding complexity to reduce motor load during the acquisition phase. However, this score should function as a guiding principle rather than a rigid rule; individual performance in **Childhood Apraxia of Speech (CAS)** is highly variable, and target selection must always account for the child's specific motor breakdown patterns, prosodic demands, and functional communication needs.

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1. Introduction: The Clinical Imperative for Vowel Quantification

The assessment and treatment of pediatric speech sound disorders (SSD) have historically been dominated by the analysis of consonant production. Standardized metrics, such as the *Percentage of Consonants Correct (PCC)*, provide robust tools for quantifying severity. However, this consonant-centric focus has led to a systematic neglect of the vowel system in clinical diagnostics.

This oversight is particularly detrimental when assessing children with motor speech disorders. In these populations, vowel errors—including distortions, inventory constraints, and diphthong reductions—serve as primary diagnostic markers.

The **Oral Motor Complexity Score v.2** addresses this critical gap. It combines established consonant acquisition norms with a new analysis of **biomechanical 'cost'**. The complexity of a vowel is not merely a phonological feature but a reflection of the motor demand required to produce it. This 'cost' is determined by:

- The degree of **jaw grading**.
- The independence of the tongue from the mandible (**dissociation**).
- The management of articulatory **trajectories** over time.

2. The Scoring System (Hybrid Model)

The complexity profile of a target word is determined by calculating a Total Motor Score (TMS) and then applying two additional structural progression rules to guide target selection.

The Formula **T**otal **M**otor **S**core (**TMS**) = Consonant Acquisition + Consonant Place + Vowel Kinematics

- **Where: V**owel **K**inematics **S**core = Base Vowel Score x Context Multiplier

Factor 1: Consonant Acquisition Score

Consonants are scored based on the typical age of acquisition.
The scores of **all** consonants in a word are summed.

- **Score 1 (Early - Ages 2–3):** /b/, /p/, /m/, /n/, /w/, /h/
- **Score 2 (Mid - Ages 3–4):** /t/, /d/, /k/, /g/, /f/, /ŋ/, /j/ (“y”)
- **Score 3 (Later - Age 5):** /v/, /s/, /z/, /ʧ/ (“ch”), /ʤ/ (“j”)
- **Score 4 (Latest - Age 6+):** /l/, /r/, /ʃ/ (“sh”), /ʒ/ (“measure”), /θ/, /ð/

Factor 2: Consonant Place of Articulation Score

When consonant scores are equal, this factor determines relative difficulty based on visibility and motor precision.
Scores for **all** consonants in the word are summed.

- **Score 1 (Front/Bilabial):** /b/, /p/, /m/
- **Score 2 (Middle/Alveolar/Dental):** /t/, /d/, /n/, /s/, /z/, /l/, /r/, /f/, /v/
- **Score 3 (Back/Velar/Palatal):** /k/, /g/, /ŋ/, /ʃ/, /ʒ/, /j/, /h/

Factor 3: Vowel Kinematics Score

Vowels are scored by calculating a **Biomechanical Base Cost** and adjusting it with a **Context Multiplier**.

A. Determine Base Vowel Score:

- **Score 1 (Physiological Baseline):** Maximal ballistic jaw movement or neutral state (/ɑ/, /ə/).
- **Score 2 (Anchored Vowels):** Jaw closed/stable; utilizes tactile feedback from palate (/i/, /u/).
- **Score 3 (Graded Vowels):** Active jaw positioning in a mid-range, unsupported by skeletal anchoring (/o/, /e/, /æ/).
- **Score 4 (Fine Tuning):** Lax vowels without anchoring; short diphthongs (/ɪ/, /ɛ/, /ʊ/, /ʌ/, /eɪ/, /oʊ/).
- **Score 5 (High Velocity):** Long trajectories, semivowels, rhotics (/aɪ/, /aʊ/, /j/, /w/, /ɝ/).
  Note: While /j/ and /w/ are phonetically consonants, in this kinematic framework they are treated as high-velocity vowel-like glides.

B. Apply Context Multiplier:

The Context Multiplier scales the base kinematic cost to reflect real articulatory demands.

- **x 0.5 (Facilitative):** Surrounding sounds support the target tongue position (e.g., Alveolar + Front vowel).
  Note: In highly facilitative contexts, the final Vowel Kinematics Score may drop below the Base Score, reflecting reduced motor effort.
- **x 1.0 (Neutral):** Standard context. The kinematic cost is equal to the Base Score.
- **x 2.0 (Inhibitory):** Surrounding sounds conflict with the target position (e.g., Mismatched place; Post-vocalic liquids), doubling the motor planning load.

Factor 4: Cluster Rule Consideration

- **Group 1:** The target sound occurs outside a consonant cluster (e.g., “bee”). Simpler articulation.
- **Group 2:** The target sound occurs within a consonant cluster (e.g., “brick”). More complex.

Factor 5: Word Shape Order Consideration

- **Simpler word shapes:** V (vowel), CV (consonant-vowel), VC (vowel-consonant), CVCV (reduplicated)…
- **More complex word shapes:** CVCC, CCVC, CCVCC, CCVCV …

3. Word Examples (Applied v.2 Scoring)

The following examples illustrate how the **Vowel Kinematics Score** impacts the Total Motor Score using the updated multipliers.

Clinical Note:
In this framework, absolute numbers are less important than relative complexity.
Note how a facilitative context can reduce a vowel's contribution, while inhibitory contexts can drastically spike the difficulty.

1. Bee (/bi/)

- **Consonants:** /b/ (Score 1) + Bilabial (Score 1) = **2**
- **Vowel Kinematics (/i/):** Base 2 (Anchored) × Neutral 1.0 = **2**
- **TOTAL MOTOR SCORE (TMS): 4**
  - **Cluster:** Group 1
  - **Shape:** CV - Simpler word shapes

2. Bin (/bɪn/)

- **Consonants:** /b/ (1) + /n/ (1) + Places (3) = **5**
- **Vowel Kinematics (/ɪ/):** Base 4 (Fine Tuning) × Facilitative 0.5 = **2**
- **TOTAL MOTOR SCORE (TMS): 7**
  - **Cluster:** Group 1
  - **Shape:** CVC - simpler word shapes

Rationale:
Despite /ɪ/ being a difficult lax vowel, the facilitative alveolar context (/n/) creates an anchor, significantly lowering the motor cost.

3. Bulb (/bʌlb/)

- **Consonants:** /b/ (1) + /l/ (4) + /b/ (1) + Places (4) = **10**
- **Vowel Kinematics (/ʌ/):** Base 4 (Fine Tuning) × Inhibitory 2.0 = **8**
- **TOTAL MOTOR SCORE (TMS): 18**
  - **Cluster:** Group 2
  - **Shape:** CVCC - complex word shapes

Rationale:
The score jumps drastically.
The framework identifies that the /l/ in the coda creates a high motor planning load for the vowel.

4. Brick (/brɪk/)

- **Consonants:** /b/ (1) + /r/ (4) + /k/ (2) + Places (6) = **13**
- **Vowel Kinematics (/ɪ/):** Base 4 (Fine Tuning) × Inhibitory 2.0 = **8**
- **TOTAL MOTOR SCORE (TMS): 21**
  - **Cluster:** Group 2
  - **Shape:** CCVC - complex word shapes

Rationale:
Represents high-level complexity:
Late consonants, a cluster, and a vowel trajectory that requires rapid cross-quadrant movement.

4. Scientific Framework

This section presents the theoretical evidence supporting the modifications to the vowel component within the Hybrid Model, where vowels are adapted to reflect motoric complexity while retaining consonant scoring from the original framework.4.1 Anatomical Foundations: The "Moving Target"

To accurately score vowel complexity, one must understand that the pediatric vocal tract is structurally distinct from the adult tract.

- **Vocal Tract Length (VTL):**
  The VTL in neonates is approximately **6 to 8 cm**, compared to **15–18 cm** in adults. This shorter tube produces significantly higher formant frequencies.
- **The Moving Target Hypothesis:**
  As the vocal tract lengthens, the child must constantly recalibrate their internal somatosensory models. Vowel distortions in CAS may reflect a failure to update these internal models amidst anatomical growth.
- **Laryngeal Descent:**
  In infants, the high larynx (C2-C3) limits pharyngeal space. By adolescence, it descends to C6. This descent creates the space required for tongue root retraction used in low-back vowels like /ɑ/ and /ɔ/.

4.1 Motor Control Variables

The Kinematic Framework utilizes concepts from "Frame & Content" theory and Articulatory Phonology to define complexity.

- **Mandibular Control (Vertical Dimension):**
  - *Ballistic (Low Complexity):*
    Vowels like /a/ and /i/ utilize the natural endpoints of jaw motion. Physical stops *may* provide proprioceptive anchoring, theoretically reducing motor load.
  - *Graded (High Complexity):*
    Mid-vowels (/e/, /o/) require **Jaw Grading**. The child must actively position the jaw in a mid-range, unsupported by skeletal anchoring (gravity antagonist).
- **Lingual-Mandibular Dissociation:**
  - *Coupled:*
    The tongue rides the jaw (e.g., /a/).
  - *Decoupled:*
    The tongue moves independently. Producing /i/ with a slightly lower jaw requires active tongue elevation. Failure to dissociate is a hallmark of immature or disordered motor control.
- **Trajectories (Distance & Velocity):**
  - ***Complexity*** is a function of Euclidean distance.
    The diphthong /aɪ/ involves maximal articulatory excursion from low-back /ɑ/ to high-front /ɪ/, requiring high velocity and precise timing.
  - ***Monophthongization*** (e.g., producing /bɑk/ instead of /baɪk/) is considered a compensatory strategy that reduces motor load by transforming a dynamic trajectory into a static vowel posture.

4.2 Developmental Chronology & Limitations

The scoring hierarchy mirrors natural acquisition, with Corner Vowels (/i/, /u/, /ɑ/) stabilizing first, followed by Lax Vowels, and finally Rhotics.

Limitations of the Framework:
While plausible, the specific hierarchy of the Vowel Kinematics Score is currently theoretical. There are no published studies confirming that /e/ is universally "harder" than /ɑ/ for all children with CAS, as individual variability in motor planning is significant. Furthermore, clinical success relies on multifactorial intervention (prosody, intensity, feedback) rather than target selection alone. Future research is required to validate these scoring metrics against kinematic instrumentation, such as ultrasound imaging.

5. Clinical Observations: Balancing Complexity with Functionality

While this framework emphasizes the quantification of motor difficulty, successful intervention requires balancing *biomechanical constraints* with *functional communication goals*.

5.1 The Motor–Functional Paradox

Children with CAS struggle to plan and sequence the movements required for speech. This is why the framework quantifies variables such as jaw grading, lingual dissociation, and articulatory trajectory. However, the child's goal in therapy is not simply to produce movements accurately—it is to **communicate successfully and be understood**.

If a target word is motorically easy (low **TMS**) but has little meaning or usefulness in the child's daily life, mastering that word may have **minimal impact on overall intelligibility or functional communication**. In other words, accurate production alone does not guarantee meaningful communication.

5.2 The "Functional Override"

For children with severe CAS and significantly reduced intelligibility, the immediate clinical priority should be **functional communication**. This often requires targeting high-frequency, high-impact words (e.g., *"stop," "help," "mine," "go"*), even when those words contain motorically complex features such as clusters, mid-vowels, or rapid transitions.

Early success in being understood—by caregivers, peers, and teachers—supports motivation, participation, and confidence, while also providing a meaningful and natural context for practicing motor planning skills.

5.3 Progressive Integration

Once a basic level of functional intelligibility is established, the **Oral Motor Complexity Score** becomes the primary framework for systematic expansion. Clinicians can then use the scoring system to intentionally scaffold motor difficulty, gradually introducing more complex vowels, syllable shapes, and articulatory transitions as the child's motor planning abilities stabilize and improve

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6. Conclusion

The **Oral Motor Complexity Score v.2** offers a structured, biomechanical lens for assessing pediatric speech disorders. By integrating kinematic principles—such as jaw grading and trajectory cost—into target selection, clinicians can potentially improve intervention planning for children with complex motor speech deficits. This framework serves as a step toward more precision-based diagnostics in Speech-Language Pathology, bridging the gap between theoretical motor control and practical therapy planning.

Further Resources for In-Depth Study

1. SLPA.ca: Practical Resources

- **Oral Motor Complexity Score & Motor Speech Disorders** — SLPA.ca. Practical guides and structured target words for children with CAS and other motor speech disorders.
  https://slpa.ca/en-us/disorders/motor-speech-disorders/apraxia-of-speech/read-this-first

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2. Child Speech Acquisition & Consonant Norms

- *Children's English Consonant Acquisition in the United States: A Review* — ASHA Journals.
  https://pubs.asha.org/doi/10.1044/2020_AJSLP-19-00168
- *Children's Speech Acquisition Overview* — Charles Sturt University.
  https://cdn.csu.edu.au/__data/assets/pdf_file/0006/227652/Speech-acquisition-summary.pdf

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3. Vowel Development & Anatomy

- Vorperian & Kent (2007). *Vowel Acoustic Space Development in Children: A Synthesis of Acoustic and Anatomic Data.*
  https://pmc.ncbi.nlm.nih.gov/articles/PMC2597712/
- *The Descended Larynx and the Descending Larynx* — J-Stage.
  https://www.jstage.jst.go.jp/article/ase/126/1/126_180301/_html/-char/en
- *The Effects of Larynx Height on Vowel Production are Mitigated by Active Control of Articulators* — ResearchGate.
  https://www.researchgate.net/publication/332788524_The_effects_of_larynx_height_on_vowel_production_are_mitigated_by_the_active_control_of_articulators

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4. Motor Speech & CAS Approaches

- *Dynamic Evaluation of Motor Speech Skill (DEMSS) Manual* — Brookes Publishing.
  https://products.brookespublishing.com/Dynamic-Evaluation-of-Motor-Speech-Skill-DEMSS-Manual-P1100.aspx
- *Dynamic Temporal and Tactile Cueing (DTTC)* — Child Apraxia Treatment.
  https://childapraxiatreatment.org/dttc/
- *Childhood Apraxia of Speech: Hierarchy of Support* — Sarah Lockhart Speech.
  https://www.sarahlockhartspeech.com/blog/cashierarchy

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5. Vowel & Diphthong Complexity

- *Vowel Dispersion in English Diphthongs: Evidence from Adult Production.*
  https://journals.linguisticsociety.org/proceedings/index.php/amphonology/article/download/3680/3384/4595
- *Understanding Diphthongs: The Complex Sounds of Language* — Verbalplanet.
  https://www.verbalplanet.com/learn-english/blog/english-grammar-diphthongs-explained.asp
- *Developmental Acoustic Study of American English Diphthongs* — PMC.
  https://pmc.ncbi.nlm.nih.gov/articles/PMC5392069/
- *Centring Diphthongs – Lexical Sets for Actors* — eCampusOntario Pressbooks.
  https://ecampusontario.pressbooks.pub/lexicalsets/chapter/review-centring-diphthongs/

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6. Jaw Grading & Motor Control

- *The Sequential Development of Jaw and Lip Control for Speech* — PMC.
  https://pmc.ncbi.nlm.nih.gov/articles/PMC2890215/
- *The Role of the Jaw for Feeding and Speech* — PediaStaff.
  https://www.pediastaff.com/blog/slp/the-role-of-the-jaw-for-feeding-and-speech-18322
- ARK Therapeutic: *How to Practice Vowels & Jaw Heights.*
  https://www.arktherapeutic.com/blog/how-to-practice-vowels-jaw-heights/
- *Q&A – Jaw Grading & Stability* — ARK Therapeutic.
  https://arktherapeutic.wordpress.com/2011/06/16/qa-jaw-grading-stability/

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7. Clinical Assessment & Tools

- *Vowel Errors Produced by Preschool-Age Children on a Single-Word Test of Articulation* — PMC. https://pmc.ncbi.nlm.nih.gov/articles/PMC8285462/
- *KPST Assessment Tool* — TheraPlatform. https://www.theraplatform.com/blog/1107/kpst
- *Effect of Complexity on Speech Sound Development: Evidence from Meta-Analysis Review of Treatment-Based Studies* — Frontiers. https://www.frontiersin.org/journals/psychology/articles/10.3389/fpsyg.2021.651900/full