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Motor Issues in Specific Language Impairment: a Window into the Underlying Impairment

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Abstract This paper reviews the findings of recent studies examining the motor abilities of children with specific language impairment (SLI). Standardized measures of motor ability confirm that children with SLI exhibit deficits in fine and gross motor skill, both simple and complex. These difficulties also extend to speech-motor ability, particularly with the control of their articulatory movements. Communicative gesturing, on the other hand, does not appear to be significantly impacted in SLI. Some of the latest studies reviewed in this paper have examined motor processes supported by procedural memory, which is argued to be impaired in SLI. The results of these studies indicate that children with SLI have difficulty with motor sequence learning, but may show deficits in other procedural motor processes as well. Despite significant progress with understanding the motor issues in SLI, future studies are needed to hone in on the nature of this impairment.

Keywords Specific language impairment · Motor deficits · Fine and gross motor ability · Speech-motor ability · Manual communicative gesture · Procedural deficit hypothesis

Introduction

Individuals with specific language impairment (SLI) exhibit age-appropriate development except for difficulties with language that cannot be explained by neurological damage, social/emotional disorders, poor language exposure, hearing loss, or oral-motor dysfunction [1, 2]. Previous research has established that the primary language difficulties of individuals with SLI pertain to syntax [3, 4], morphology [5, 6], and phonological processing [7–9]. Though the term SLI implies deficits limited to language, several studies have also reported motor impairments [10]. In this paper, we argue that examining motor deficits in SLI will bring us closer to understanding

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the underlying mechanisms of this syndrome. Identifying the cause or causes of SLI is an important objective given that the well-being of so many children is at stake. About 7 % of 5-year-olds are diagnosed with SLI [11]. Understanding the causes of this disorder that is associated with poor academic attainment [12–14], risk of psychiatric disorders [12, 15, 16] and difficulty maintaining gainful employment and positive social relationships [17] is an important priority. Our aim is to review recent studies that have assessed the fine and gross motor ability, speech-motor ability, and manual gestures in individuals with SLI.

Empirical studies examining the motor abilities of children with SLI go as far back as the mid-1960s. By the late 1990s, only a handful of studies provided evidence suggesting that children with SLI exhibited motor deficits. However, a comprehensive literature review by Hill [10], published in 2001, revealed that the prevalence of motor impairment in SLI was much higher than the earlier work had suggested.

Hill [10] reviewed nearly 30 studies that explicitly examined the motor abilities of children with SLI. Her summary of the literature indicated that the motor deficits in SLI were quite extensive and include difficulties with (1) fine motor skill as measured by tasks of finger opposition, bead threading, and peg moving [18–20]; (2) gross motor ability as measured by tasks of balance, aiming, catching, and hopping [20, 21]; and (3) praxis ability as measured by the production of familiar and unfamiliar gestures and, especially, the production of sequences of familiar gestures [22–24].

Based on these findings, Hill [10] reached two main conclusions. First, she suggested that the comorbid motor deficits in SLI were likely the norm, not the exception. Second, she suggested that domain-general explanations of SLI were better suited to explain the language and motor deficits in SLI than was the classical language-specific hypothesis.

A similar argument was later made by Leonard and Hill [25] after reviewing studies exploring the effects of motor development on social, cognitive, and language abilities in typical development and in neurodevelopmental disorders including SLI. Their review of the SLI studies revealed significant correlations between standardized measures and parental reports of motor development and language measures including communication ability, expressive language scores, and articulation. Leonard and Hill [25] speculated that these significant relationships suggest that neural mechanisms underlying motor development may be shared by other areas of development like language and social development and further prompted future studies to corroborate their hypothesis.

In the present review, we will discuss studies that focused on fine and gross motor abilities, speech-motor ability, and manual gestures in individuals with SLI. Our review not only leads us to a conclusion that coincides with Leonard and Hill's [25] main insight, but additionally considers studies exploring speech-motor ability and communicative gesturing and offers new insights into the neurocognitive mechanisms underlying language and motor development, which were not previously discussed in Leonard and Hill's review [25].

Fine and Gross Motor Ability

In the decade following Hill's [10] review, several studies added more information about the comorbidity of motor impairment in SLI [26–29]. The studies, which are discussed below, examined the performance of children with SLI using standardized assessments and tasks of motor ability to further confirm the presence of generalized motor deficits in SLI.

Two studies examined the presence or absence of clinically significant motor deficits in children with SLI [30, 31•]. Finlay and McPhillips [30] compared the motor abilities of children with SLI to age-matched children with typical language development and age-matched children who had not been clinically identified as having SLI but exhibited low language abilities. The objective of their study was to determine whether children with SLI experienced greater motor difficulties than children without an SLI diagnosis. Finlay and McPhillips [30] used the Movement Assessment Battery for Children (MABC-2) [32] and found that children with SLI scored significantly lower on all subscales of the MABC-2 than did the low language and typical comparison groups. These authors also reported that half the children with SLI were labeled "at risk" for motor difficulties, while about a third of children with SLI were not just "at risk" but also presented with significant motor difficulties [30].

Another pair of investigators, Flapper and Schoemaker [31•], offered similar results. They examined the comorbidity of developmental coordination disorder (DCD) in children with SLI. DCD is a diagnosis applied to children whose motor skill development is either delayed or impaired such that it disrupts academic performance and/or daily activities. A common criterion for DCD is a score in the 15th percentile on standardized measures of motor ability such as the MABC [33]. Using the MABC, Flapper and Schoemaker [31•] found that the total MABC scores of about 32 % of children with SLI fell below the 15th percentile, indicating that about a third of children with SLI also presented with DCD. We note that similar to SLI, the cause of DCD is unknown and often co-occurs with other conditions such as attention deficit hyperactivity disorder (ADHD) and dyslexia [34].

Other recent studies have focused on understanding the deficits in specific motor areas in children with SLI [35, 36]. Vukovic, Vukovic, and Stojanovik [35] assessed coordination and imitation in children with SLI using subtests from the McCarthy's Scales of Children's Abilities [37] and the Test of Imitation of Movements [38], respectively. The McCarthy's Scales of Children's Abilities measured coordination of legs (e.g., walking backwards, skipping, etc.) and coordination of arms (e.g., catching, bouncing, and aiming a ball). The Test of Imitation of Movements consists of two main subtests: (1) imitation of simple movements (e.g., gestures with hands and arms/elbows) and (2) imitation of complex movements (e.g., manipulation of fingers and hands). Vukovic et al. [35] showed that children with SLI scored significantly lower on measures of coordination and imitation in comparison to their age-matched typically developing (TD) peers.

Zelaznik and Goffman [36] reported results consistent with Vukovic et al. [35]. They examined the motor abilities, and specifically, motoric timing, of children with SLI. Using the Bruininks–Oseretsky Test of Motor Proficiency (BOT) [39], Zelaznik and Goffman [36] found that children with SLI performed more poorly than age-matched TD children across all subsections of the test, which consists of several coordination-based tasks. Interestingly, on the measures of timing, which included circle drawing and finger and hand tapping, these researchers found that the timing precision of children with SLI was comparable to that of TD children [36].

Notwithstanding the last result, the studies reviewed in this section, as a whole, confirm that children with SLI also tend to have motor deficits. The range of motor deficits seen in the children with SLI is wider than was picked up at the time of Hill's review [10] when much of the new research had not yet been done. So, in addition to the difficulties with fine and gross motor and praxis abilities that Hill [10] discussed, we can add that children with SLI also show significant difficulties with coordination and imitation [35, 36], though motoric timing may be unaffected in SLI, at least insofar as motoric timing was assessed via the tasks used by Zelaznik and Goffman [36].

Speech-Motor Ability

Producing language requires motor control of the speech apparatus, in which case, given the evidence for motor impairments in children with SLI, it becomes important to check whether speech-motor ability per se is affected in SLI. The literature on this topic is sparse. Two notable studies were conducted, however, by Goffman [40, 41], who found that children with SLI exhibited greater variability in their articulatory movements than did age-matched TD children. Since then, a few studies have been motivated to further explore speech-motor ability in SLI.

Recently, Andrade et al. [42] examined speech rate (word and syllables per minutes) and level of disruption (e.g., frequency of hesitations, repetitions, and revisions) in the speech production of children with SLI. They found that speech rate was significantly slower in children with SLI relative to age-matched TD children between the ages of 3 and 4 years, but they also found that this difference was no longer evident in children between the ages of 5 and 7 years of age. Level of disruption, on the other hand, was not significantly different between children with SLI and TD children at any age, although the TD children aged 4 years and older actually hesitated significantly more often than did the children with SLI. Andrade et al. [42] suggested that the increased hesitations in the TD children reflected their attempts to compose more complex sentences. We hypothesize that with significantly weaker language abilities, children with SLI produce simpler sentence structures [3, 4], which might explain why there was less hesitation in children with SLI than in TD children. Assessing the linguistic complexity of sentences produced by children from the two groups seems to us to be a fruitful subject for future research.

Apart from studies of speech timing, other studies have focused on articulatory control of speech motor movements in children with SLI. Archibald, Joanisse, and Munson [43•] examined speech motor control during nonword repetition in children with and without SLI. They had children repeat nonwords from the Children's Test of Nonword Repetition [44] and perturbed the children's speech motor movements using gummy bears as bite blocks. Both the SLI and age-matched TD groups repeated simple nonwords (one syllable) comparably with and without the bite blocks. However, the bite block had a greater impact on complex nonword repetition (two to five syllables) for the children with SLI than it did for the controls. Based on these findings, we hypothesize that while elementary speech motor movements are not compromised in children with SLI, motor planning may be affected. It has been suggested that successful speech production is dependent on several underlying factors, one of which is motor planning [45–47]. It is, therefore, possible that the motor planning difficulties experienced by children with SLI become noticeable as the complexity of speech increases.

This hypothesis was confirmed by DiDonato Brumbach and Goffman [48•], who examined articulatory stability and duration of simple and complex syntactic structures vis-à-vis fine and gross motor ability in children with SLI and age-matched TD children. DiDonato Brumbach and Goffman [48•] used a priming task to elicit target phrases including the same word as either a preposition (simple structure, e.g., walk *over* the book) or a particle (relatively complex structure, e.g., tip *over* the tower) in children. They also administered the Peabody Developmental Motor Scales (PDMS) as a measure of fine and gross motor ability [49]. They reported that the durations of movements were comparable between children with SLI and TD children. The articulatory movements, however, were less stable in children with SLI independent of phrase type. Additionally, children with SLI scored significantly lower than their age-matched peers on the PDMS. A correlational analysis showed that weaker fine motor ability was related to greater articulatory variability. The results for language ability, however, were inconclusive. While language errors were positively correlated with articulatory variability when substituting a particle for a preposition in one sentence frame, this correlation was not found for other sentence frames. This study suggests that children with SLI experience difficulty with their articulatory movements during speech production.

These findings, like all the findings reviewed in this section, suggest that despite the absence of basic oral-motor dysfunction in children with SLI, these children do have some problems with speech rate and articulatory control, especially when producing sequences of sounds and words with increased complexity [43•, 48•]. Whether these difficulties are speech-specific is unclear, however.

Manual Gestures

Hill's [10] review indicated that children with SLI present with deficits in praxis ability, particularly in the imitation of manual gestures. Subsequent studies have followed up on this observation.

Botting, Riches, Gaynor, and Morgan [50] explored the quality of gestures in relation to motor and language abilities in children with and without SLI. They showed children images of real objects and events (e.g., weather) and asked the children to produce a gesture that represented the target object or event. These gestures were subsequently evaluated by raters who assigned a score to each gesture based on how easily recognizable the target object or event was from the gesture (gesture production scores). The resulting gesture production scores did not significantly differ between children with SLI and age-matched TD children. Furthermore, correlational analyses revealed that for TD children, gesture production scores were only significantly related to fine motor ability while for children with SLI, gesture production scores were only significantly correlated with language ability. Botting et al. [50] thus concluded that children with SLI do not appear to show any special difficulties producing representational gestures, though the specific relation between gesture production and motor and language abilities may differ in children with SLI and in TD children.

Similar to Botting et al. [50], Iverson and Braddock [51] examined gesture production and motor ability and the association of these factors to language ability in children with SLI. Children were told a story by their caregiver and then were asked to narrate the story to an inanimate object. The children with SLI performed poorly across all four measures of motor ability, consistent with previous studies [26–30, 31•, 35, 36], but as concerns gesture production, trends toward greater frequency of gesture and gesturing rate were observed in children with SLI relative to age-matched controls. Additionally, regression analyses revealed a negative association between frequency of gesture production and expressive language ability for the children with SLI, so the weaker the child's language abilities, the more they gestured. On the other hand, a positive relationship was observed between fine motor ability and language ability, suggesting that the weaker the child's language abilities, the weaker their fine motor abilities. Iverson and Braddock [51] took these findings to suggest that children with SLI use gesture to support their poor verbal communication, but their fine motor ability may limit the quality of their gesture production.

Taking a slightly different approach to the analysis of manual gestures, Sanjeevan, Mainela-Arnold, Alibali, and Evans (under review) examined temporal aspects of speech and manual communicative gesture in children with SLI. They found that the temporal alignment of gesture and speech and gesture duration were not significantly different in SLI and age-matched TD children. Sanjeevan et al. suggested that despite reports of praxis and coordination problems in SLI, the temporal aspects of gesture-speech pairs in spontaneous speech in children with SLI are comparable to those of TD children.

In general, the three studies reviewed in the present section suggest that manual communicative gesturing is essentially unimpaired in SLI and perhaps not significantly affected by whatever subtle motor deficits may otherwise be associated with SLI [50, 51]. This outcome suggests that gestural limitations may be less significant than speech motor problems in SLI.

Procedural Deficit Hypothesis

So far in this review, we have mainly focused on the motor-control side of SLI. Now, we turn to more cognitive aspects of the syndrome, asking as others have before, whether SLI might reflect difficulties in working memory capacity [52], general processing speed [53, 54], or attention [55–57]. If any of these factors were responsible for SLI, one would not need to propose parallels between the language and motor deficits in SLI.

The only hypothesis clearly predicting a cognitive deficit that contributes to motor deficits in SLI is Ullman and Pierpont's [58] procedural deficit hypothesis (PDH). According to the PDH, the procedural memory system underlies rule-governed aspects of language learning [59] and will, if impaired, give rise to both language and motor deficits. Furthermore, according to the PDH, damage to the basal ganglia and striatum, in particular, results in procedural-performance limitations expressed in both sensorimotor and cognitive spheres [58].

A number of studies have investigated the PDH by examining the performance of children with SLI on the serial reaction time (SRT) task. This is a paradigm used to examine visuo-motor sequence learning [60•]. In this task, subjects are exposed to a repeating sequence of visual–spatial stimuli. Participants in this task may not explicitly notice the fact that the sequence repeats. Nevertheless, the reaction times decrease as the sequence repeats and increases if the sequence is disrupted (i.e., a stimulus does not appear when, statistically, it should have).

Children with SLI take longer to learn such sequences, as evidenced by their longer reaction times than seen in age-matched TD children [61, 62•, 63–66]. A couple of studies have not found such differences [67, 68], but a recent meta-analysis by Lum, Conti-Ramsden, Morgan, and Ullman [60•] of 8 SRT studies showed that performance on this task was significantly different between children with SLI and TD children, with an average effect size of 0.33. Their analysis also revealed that age and amount of exposure to the sequence were factors that affected performance. Specifically, as children received more exposure to the sequences, the differences between the groups decreased. This finding echoes the observation that while children with SLI show delayed motor sequence learning, they can match TD children in motor sequence performance if they are given more exposure to the sequences to be learned [60•].

Two other studies have explored whether deficits in SLI extend to non-sequence-specific procedural tasks. Adi-Japha, Strulovich-Schwartz, and Julius [69] examined the acquisition and consolidation of an invented letter in children with and without SLI. This task was specifically chosen to represent the motor learning that occurs while children learn how to write and was administered in phases (pre-training, training, post-training, consolidation, and retention). The authors found that accuracy was consistently comparable between the SLI and age-matched TD children in all phases. Performance speed (the time taken to write the letter), however, differed between the two groups. In the pre-training phase, only TD children showed a continuous decrease in performance speed, while children with SLI did not. During the training phase, a decrease in performance speed was found for both children with SLI and TD children. By the post-training phrase, performance speed had plateaued for both groups. Furthermore, Adi-Japha, Strulovich-Schwartz, and Julius [69] examined consolidation and retention of the invented letter. Consolidation of the invented letter was defined as the gains (increased performance speed relative to their performance in the preceding phase) made between immediate post-training and 24 h post-training. Consolidation gains were only observed in TD children, but not in children with SLI. Interestingly, retention, defined as the gains made between 24 h post-training and 2 weeks post-training, were only observed in children with SLI, but not in TD children. Based on these findings, it appears that procedural motor skills, such as learning to write a letter, that do not involve sequence-specific information, might also be affected in children with SLI.

Conflicting results were reported, however, by Hsu and Bishop [62•], who were also interested in establishing whether or not deficits in SLI were related to performance on sequence-based procedural tasks. They compared children with SLI to age-matched and grammar-matched TD children on three measures, among which were the SRT and pursuit rotor tasks. The SRT task served as the sequence-specific procedural measure, whereas the pursuit rotor task was used as a non-sequence-based procedural measure. The objective in the pursuit rotor task is to maintain contact with a target located on a revolving disc. This involves using visual feedback to adjust the orientation of the hand to maintain contact with the revolving target. This hand–eye coordination task is a test of motor adaptation often used to test procedural learning.

As expected, the children with SLI showed significantly slower learning on the SRT task than the TD children. However, the children with SLI were not significantly different from their age-matched peers on the pursuit rotor task. Based on these results, Hsu and Bishop [62•] concluded that deficits in SLI may be specific to sequence-based information, leaving other procedural skills such as motor adaptation unaffected.

Wrapping up this section of the present review, we conclude by stating, in accord with Hsu and Bishop [62•] and also in accord with Ullman and Pierpont [58], that SLI may reflect a problem with sequence learning and production. Motor limitations may be secondary in SLI. Sequence-learning limitations may be primary.

Conclusions

Since Hill's [10] seminal review, SLI researchers have made significant progress in characterizing the etiology of SLI. Starting with the hypothesis that SLI is a specific language impairment, subsequent research has shown that it is not and that motor deficits are part of the syndrome. Then the possibility arose that the motor deficits may not be specifically motoric either, but instead the abstract, cognitive challenge of temporally extended motor production, whether it is expressed orally or via pressing keys in a serial reaction time task, may be disturbed in SLI. A number of results have confirmed this important new insight.

The question remains, however, of why fundamental motor abilities such as fine and gross motor abilities are impaired in SLI, whereas both basic and complex motor movements such as motoric timing and communicative gesturing are relatively intact in SLI as seen in this review. One answer is that the measures used to examine gestural communication and basic motor timing may not draw on the higher-level sequencing faculty that may be disrupted in SLI. Tapping a finger on a key or drawing a circle or pursuit rotor tracking are cognitively simple tasks, and the tasks used in the gesture studies described above examined the production of isolated gestures, which may not tap into sequencing faculties to the same extent as the production of sequences of actions/gestures would. This explanation is consistent with Hill et al.'s [24] findings in their examination of habitual gestures in children with SLI, DCD, age-matched controls, and IQ-matched younger controls. Habitual gestures, such as the holistic action of brushing one's teeth with a toothbrush, involve a series of movements that are executed in a specific order to achieve a specific outcome. Hill et al.'s [24] results indicated that the pattern and frequency of errors produced by children with SLI were comparable to those of children with DCD and the younger control group and significantly different from the age-matched control group. Additionally, it appears that gestural communication may rely on one or more forms of representation to support the production of communicative gestures in SLI, whereas habitual gestures may rely on different domains and processes, perhaps sequencing, that may be compromised in SLI. If a sequencing deficit did indeed exist, we might expect to see deficits in speech production. However, the involvement of sequencing in speech is not well understood. With studies only just beginning to explore the speech-motor abilities in SLI, we cannot be certain what aspects of sequencing in speech production are affected in these children.

In addition to possible sequencing deficits, the findings of the studies reviewed in this paper also suggest difficulties with motor planning in SLI. Motor planning is the ability to organize a sequence of actions needed to execute a novel skill successfully prior to execution [70]. The time taken to complete fine motor tasks such as peg moving and the successful repetition of complex nonwords can be affected by the ability to plan the most efficient path to insert pegs and organize the correct string of sounds in a nonword, respectively. Therefore, the lengthier times taken to complete peg moving tasks and the difficulties with repetition of nonwords that are often seen in children with SLI could be partially attributed to poor motor planning [19, 48•]. As far as we know, this is a novel prediction for the SLI literature. Also to the best of our knowledge, it is a new prediction for the study of development. Studies examining motor planning might therefore provide new insights into SLI and the other developmental difficulties that have been considered in tandem with it.

The prediction made above is in line with the hypothesis of Ullman and Pierpont [58] that there is a deep functional relation between motor development and language development, expressed specifically in sequencing. However, the prediction is inconsistent with, or at least not predicted by, an alternative hypothesis that deserves careful consideration as well, namely, that the deficits in the two areas of development are coincidental. Given the limited literature, it remains unclear whether the correlations between the deficits in the two areas bespeak true linkages, let alone a common cause.

In this connection, a promising avenue is to look for endophenotypes for SLI and the other disorders that were considered here. An endophenotype is "any hereditary characteristic that is normally associated with some condition but is not a direct symptom of that condition [71, p. 10]." If, via the search for endophenotypes, one or more common genetic sources could be found for SLI and other syndromes such as dyslexia where sequencing suffers in both the language and motor domains [72, 73], that outcome would further support Ullman and Pierpont's proposal. Preliminary work that has been done in this connection has suggested genetic contributions to SLI [74], though identification of candidate genes [75] has been slowed by the varied diagnostic categories for SLI [76], and more recently the suggestion of complex interactions between genetic and environmental factors [77]. It is too early to tell whether the genetic data bear critically on the sequencing view or the other views that were reviewed here.

In any case, the practical implications of current and future research exploring the motor issues in SLI are significant. An existing clinical concern is that the services delivered to children with SLI do not address the underlying problem of the disorder. This may result in language difficulties that persist in adulthood, which can contribute to poor quality of life [78]. If evidence suggests that the mechanism underlying both the language and motor deficits in SLI is procedural memory, then services can focus on strengthening procedural skills and possibly yield long-lasting improvements in the child's language and motor abilities.

A second concern is the identification of children at risk of SLI in bilingual populations. Standardized language measures are commonly used in schools to evaluate the language abilities of bilingual children. These measures, however, are often normed using monolingual populations, making it difficult to identify whether a bilingual child's language abilities are influenced by bilingual exposure or affected by language learning difficulties [79–81]. This often results in misdiagnosis of typically developing bilingual children as having SLI. To overcome this obstacle, studies have reported that both of the languages spoken by the child must be assessed [79, 81]. Considering the linguistic diversity among bilingual children in schools today, this is simply not feasible. This problem could be resolved if a non-linguistic task could predict individual differences in language ability. If accumulating evidence suggests that children with SLI do exhibit difficulties with motor abilities supported by procedural memory, then aspects of motor ability could be used to supplement identification of risk of SLI in both monolingual and bilingual children. These clinical applications warrant further work on this topic.

In conclusion, the findings of the most recent SLI studies examining motor ability confirm that children with SLI present with comorbid motor deficits. Standardized measures of motor ability have consistently shown that children with SLI perform poorly on tasks of fine and gross motor ability, including coordination and imitation [30, 31•, 35, 36]. These difficulties also appear to extend to speech-motor ability, specifically showing weaker articulatory control of speech-motor movements [42, 43•, 48•]. Interestingly, communicative gesturing and motoric timing appear to be unaffected in children with SLI [50, 36]. The exact reasons for this are currently unknown. The current characterization of the motor deficits in SLI has led researchers to explore the function of basic motor processes in this population. Thus far, there is evidence to suggest that individuals with SLI exhibit difficulties with learning sequence-specific information [60•]. These particular deficits have been attributed to impairment of the procedural memory system [58], but further investigation of the role of procedural memory in SLI is needed. Despite significant advancements in our understanding of SLI, there is still a great deal we do not know and it is our hope that this review will help advance research in this field.

Compliance with Ethics Guidelines

Conflict of Interest Teenu Sanjeevan, David A. Rosenbaum, Carol Miller, Janet G. van Hell, Daniel J. Weiss, and Elina Mainela-Arnold declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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