A Review of Statistical Learning and Developmental Disorders

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Abstract: The ability to identify and pick up regularities in the environment across different perceptual and cognitive domains is known as statistical learning (SL), and it is a key component of automatically and subconsciously acquired learning. According to language acquisition, SL is considered an important mechanism for perceiving the regularities in language. Recent work tried to find the association between deficit in SL and language impairments in developmental disabilities. This review will provide an overview of studies testing the SL abilities of participants with and without developmental disorders and discuss whether SL deficit is an underlying reason for language impairment. Considering the complexity of language development, the full picture is not available yet. The research to date on SL is informative but the overall theoretical construct tends to be unspecified. This review will discuss the vagueness in definition including complex cognitive faculties and experimental paradigms. Also, future experimental directions are provided in the end.

Keywords: Statistical learning, language acquisition, implicit learning, developmental disorders, language impairment

1. Introduction

An Effective Method of Learning In recent years, developmental and cognitive research has come to focus on statistical learning as an implicit learning mechanism. While there has been interest in SL for a century, Saffran and colleagues' seminal research [1] demonstrating that 8-month-old newborns are sensitive to transitional probabilities (TPs) of syllables in a continuous speech stream is responsible for the recent impetus in this mechanism. The article highlighted the innate sensitivity towards word segmentation of verbal inputs that can help explain why infants and children are fast language learners. The findings spurred debate and increased curiosity about the function of SL and other facets of cognition. Humans are remarkably sensitive to distributional regularities in the visual auditory, and pure tones, including neighboring or non-adjacent dependencies [2-6]. Several studies have demonstrated this. In the language domain, experiments regarding verbal and non-verbal domains have been conducted to find the relationship between SL abilities and subdomains of language skills. Studies have shown that proficient language learning requires the sensitivity and assimilation of statistical regularities present in linguistic cues. These studies include the association between SL and literacy skills in comprehension of syntax [7], letters and speech sounds [8], semantic and phonological lexical access [9], word segmentation and vocabulary of different orthographic units,

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and speech perception [10-12]. Research to date has shown the importance of SL in language acquisition. The performance of atypical and typical groups also indicated the association between language impairment in individuals with neurodevelopmental disorders. However, the inner structure and precise theoretical construct are still unclear.

2. Statistical learning and language acquisition

Natural language consists of rich arrays of recognizable and analyzable patterns (frequencies, positions, distributions, associations). In the learning process, a stream of speech can be interpreted and described as segmented syllables with specific phonotactic constraints. Infants can pick up the regularities as phonemic and phonetic sequences. After familiarization and consolidation, they internalize the patterns. For analysis of inputs, speakers of a particular language can parse the continuous speech, assimilate the patterns of conditional probabilities of phonemes, and make predictions of incoming speech. For example, orthographical properties include a set of recurrent letter sequences or combinations, such as prefixes and suffixes. English learners have been able to judge baff as more word-like than bbaf, indicating the sensitivity of the positions of double letters in written language [13-14]. Hence, empirical evidence suggests that language acquisition is highly associated with SL ability.

2.1. Measurement of SL performance

Before Saffran's research, the assimilation of patterns was assessed in implicit learning, which primarily focuses on the underlying mechanisms and innate ability in learning. Considering the milestones in language development, infants are like super learners. Simple conditioning or reinforcement cannot fully explicate language acquisition. Implicit learning is centered on knowledge acquisition without consciousness or awareness. In the language domain, procedural learning is linked with grammar learning. Statistical learning for verbal or nonverbal cues also belongs to the family of implicit learning. The evaluation of SL proficiency incorporates tasks related to rule learning. For instance, the AGL task, which Reber first developed to assess rule learning, is also linked to assessments of the statistically significant surface similarity between linguistic regularities [15]. The following tasks are employed most frequently in SL research:

2.2. Experimental paradigms and learning tasks

TP learning: Saffran et al. employed a continuous speech stream devoid of any audible cues or significant pauses. The linguistic units with quantifiable statistical regularities that differentiate between more chance-based sound sequences that cross word boundaries and recurrent sound sequences that make up words are passively presented to participants [1]. When two sounds in a word follow one another, the transitional probability from one sound to the next is usually the highest. Following a brief familiarization phase, the capacity to internalize the patterns is evaluated using a two-alternative forced choice (2AFC) test phase.

Artificial-grammar-learning (AGL) task: Artificial-grammar-learning (AGL) task: The paradigm was originally developed to measure implicit learning ability [16], participants were typically presented with sequences of stimuli generated by a miniature grammar, such as a non-sense syllabus. Then they are asked to classify a new set of sequences according to whether they are consistent with the grammatical rules with the old ones.

Serial-reaction-time (SRT) task: Members are given groupings of visual improvements showing up consecutively in a few areas on the screen and are expected to press a comparing button to the pertinent area as fast as could be expected [17]. Across organized blocks, upgrades might follow a decent grouping. In this way, members can foresee the area of the upgrade. Regularly, reaction times

for organized groupings are contrasted, and reaction times for irregular successions, mirror the degree of learning.

According to the review, over 60% of SL research followed the approach of TP learning with variations of stimulus [18]. For recent web-based experiments, the auditory tasks are still close to Saffran's study [1]. The task each contains auditory linguistic (Syllable), auditory nonlinguistic (Tone), visual linguistic (Letter), or visual nonlinguistic (Image) stimuli, including familiarization phases and test phases as seen in commonly used triplet-learning paradigms [5], [19-20].

3. Statistical learning in DD and SLI

Children with developmental dyslexia (DD) and Specific Language Impairment (SLI) dislike perusing and spelling. Individuals with DD showed various degrees of shortfall in the advancement of perusing abilities that are gotten from tactile hindrances, neurological issues, or deficient tutoring. SLI and DD are particular yet possibly comorbid formative language problems. A shortfall in phonological handling is firmly connected with dyslexia yet not with SLI when it happens without even a trace of dyslexia [21]. Kids with DD performed all the more ineffectively on semantic and tone arrangement factual learning assignments than youngsters in the correlation bunch. Lum et al. synthesized the data from 14 published studies comparing individuals with DD and their age-matched TD controls in serial reaction time (SRT) tasks [22], which assessed the participants' reaction time difference to randomly ordered and sequentially ordered stimuli [17]. The results showed that individuals with DD performed significantly worse than TD controls on sequence learning in an SRT task [23]. Evans et al. measured the SL performance of school-aged children with SLI [24]. They passively listened to a stream of continuous syllables with only statistical cues to word segmentation. With the control of age and nonverbal IQ, the results showed that children with SLI behaved more poorly on auditory SL tasks. Tomblin et al. tested SL ability on visual materials [25]. The results are consistent with Evan et al.'s, indicating the deficit in SL ability. Furthermore, according to a metaanalysis of SL ability in different domains, children with SLI exhibit difficulty in tracking sequential patterns that are both linguistic and nonlinguistic. The consistency of poor performance in different cognitive domains suggests that the SLI group may have a domain-general deficiency in most learning tasks with the need for pattern assimilation [22], [26]. The inadequate ability to pick up regularities and longer reaction time may be associated with SL performance and native language acquisition.

4. Statistical learning and ASD

Autism spectrum disorder (ASD) is described by center shortages in friendly correspondence and by limited interests and tedious ways of behaving [27]. In the current definition of ASD, recent theories consist of a set of broad behavioral and cognitive traits [28-30]: insistence on sameness, social interaction, sensory hypersensitivities, difficulties interacting with moving objects, and difficulties with theory of mind. In autistic children, the proportion of verbal type is 75% [20]. In the current diagnosis, language impairment is not a key standard. However, impairments in pragmatics, semantics, morphology, phonology, and syntax have been observed among many individuals with ASD [31]. Additionally, the predominant variety among mentally unbalanced youngsters has been noticed [32]. The presence of language weakness in mentally unbalanced kids may be an outcome of abnormal learning components including SL [33]. Research has revealed divergent findings in terms of whether ASD is associated with atypical SL [34]. Some studies showed that autistic individuals have intact SL ability. Roser et al.conducted the visual SL experiment on autistic adults, children, and age-matched control groups [35]. Participants were approached to see multi-shape exhibits made out of an irregular mix of sets of shapes that were each situated in a proper spatial game plan. The

outcomes showed that all member gatherings could segregate sets of shapes. Also, learning these shape matches with high covariation was more predominant in mentally unbalanced grown-ups than in age-matched controls, while execution in medically introverted kids was the same as in controls. In later exploration [36], mentally unbalanced kids showed similar examples of execution as youngsters with the regular turn of events. By examining kids with a chemical imbalance and SLI (explicit language issue), the general example digestion and quick abilities to plan ASD bunch are essentially better. Also, they compared the differences in the ASD group. For those who manifest language impairment (ALI), the fast-mapping skill is slightly inferior to those with normal language abilities (ALN). Some research showed atypical SL ability, often manifested as slower detection of patterns, lowered accuracies in pattern retrieval, or reduced neural activation to patterns compared to controls [37-38]. Jeste et al. examined electrophysiological responses to visual statistical learning among young children with and without ASD. The results showed reduced neural activity regarding SL [37].

The linguistic statistical learning ability is intricate with mixed findings. Autistic individuals showed disparity across auditory and visual domains [20], [39], indicating a domain-specific rather than a domain-general model in SL. Also, individual performance in auditory linguistic SL tasks is not correlated with other nonlinguistic tasks [4]. The heterogeneity of individual performance in different cognitive aspects indicates that the SL ability varies within individuals. The core deficit of social communication in the ASD group also manifests itself as difficulty in dealing with speech (e.g., human voice) rather than pure tones or computer noise [40-42]. Overall, linguistic SL tasks can serve as a paradigm to predict the ASD of linguistic phenotype with consistent evidence in the literature. However, the development of SL through life trajectories remains unclear. For an autistic group with linguistic impairments, the specific stage of learning is atypical and is also unknown due to individual differences and complexity in the SL process.

5. Theoretical Construct of SL and Language Impairments: Complexity and Vagueness

5.1. Toward a precise prediction

As the learning process mentioned above, statistical learning plays an integral part in language learning. Thus, we can make a reasonable and straightforward prediction: If there is a group difference in language acquisition, there should be consistent evidence for lower performance on SL tasks of the atypical group compared to the neurotypical group. Therefore, if statistical learning is sufficient to account for the consistent group difference between atypical and control groups, the theoretical construct needs several premises. First, the SL ability should be domain-general without high variability within different aspects of language skills. Second, performance on linguistic SL tasks is associated with language acquisition. Third, most children with linguistic-related developmental disorders have a deficit in SL. The findings of consistent group differences in the performance of linguistical SL tasks would indicate they tap the same cognitive mechanism. Assume we need to involve SL as a forecast worldview in language debilitation. Predictable experimental proof is expected to represent various areas in language securing and individual changeability in language improvement. For SLI and DD, Cleric and Snowling called attention to the high comorbidity among SLI and DD [43]. The language challenges between various demonstrative gatherings frequently cross over. In any case, the symptomatic rules are unmistakable. People with DD have a shortfall in proficiency. Individuals with SLI might show shortfalls in communication in language, like discourse discernment and cognizance. The noticed gathering level contrast in measurable learning in SLI and ASD recommends that the various appearances of language hindrances in each confusion come from various fundamental components. The ongoing discoveries are predictable with the procedural shortfall speculation of Ullman and Pierpont wherein disabilities in measurable learning represent deficiencies in rule-based parts of language [44], like phonology, morphology, and grammar. In a new report, Siegelman et al. utilized word naming assignments to gauge various parts of literacy [45]. The results suggest that developing an efficient division of labor between orthography to phonology (O-P) and orthography to semantics (O-S) is crucial for early reading success. If children can successively assimilate the O-P and O-P regularities in the learning process, they will show better performance in reading skills.

5.2. The vagueness of theoretical construction

Examination to date has demonstrated the significance of SL in the language educational experience. In any case, there is certainly not a very organized hypothesis to coordinate the experimental proof. As per Ice et al., Useful advances in any exploration field lay based on creating exact functional conditions that lead to fine-grained qualifications and all-around determined predictions [18]. There are as yet missing riddles in grasping SL and its job in learning. For instance, can exploratory SL undertakings completely address SL capacity? What is the cycle and relationship between getting consistency and obtaining information? How does the measurement of performance in a task interact with the learning process? What kind of information is the object of SL? What's the standard for such assimilation? For the relationship between SL experimental tasks and the learning process, there are some limitations. For those linguistic SL tasks, the experiment often measures the highest repetitive patterns in visual or auditory streams. However, regularities in the environment do not confine to high TP information. Furthermore, transitional probability may not solely play a part. Second, the richness and abstractness of elements are much more complex than in experimental setting settings. Regarding language, the pitch and tone may vary subtly. The syllable will have different acoustic features in real life. Also, our experiment each contains a familiarization phase for about several minutes. Learning regularities in the real world, however, spans a much larger period, mostly without consecutive repetitions. Without providing the object of assimilation in the real world, the mechanism of SL is explained by the content of the task requirements and the redescription of task performance. The bigger picture and internal process are still obscure and vague.

For the definition of SL, recent studies have argued that the statistical learning mechanism is not domain-general, as the correlation between various statistical learning tasks is rather low [19]; [4]. A consistent group difference would also strengthen the view that statistical learning is linked to reading acquisition [34]; [46]. Also, recent theoretical frameworks of SL posit that the learning of statistical information is comprised of multiple stages, including the encoding of individual stimuli from a continuous stream of input, the binding of individual stimuli into word-like units, as well as the storing of these representations for later retrieval. In the ASD group, the linguistic SL ability is rather intact. An alternative account for the disparity in the autistic group can be the lack of socio-cognitive and socio-affective awareness [47-48]. The linguistic delay or impairment can be attributed to poor joint attention and social engagement because early words are often learned in contexts where children can coordinate their attention and interests with caregivers. Compared to ASD, DD and SLI showed significant group-level differences in linguistic SL tasks.

5.3. Future directions

A valid theory of SL has to offer explanations for why organisms concentrate on a particular subset of patterns from the vast array of environmental regularities, how they perceive and integrate numerous patterns present in sensory input, how they acquire patterns that vary in size and distribution, and how they handle the significant noise inherent in sensory inputs. The experimental paradigms should simulate a real learning process. Novel methodologies and approaches are required for a full picture. For example, 2AFC questions may present a direct answer, but it does not tap into

how learning occurs and accumulates on a step-by-step basis. In real life, the assimilation and accommodation of grammatical rules are far more complicated. Also, the combination of other cognitive faculties is needed. For SLI and DD, many of the current findings of impaired SL performance could also be attributed to other cognitive abilities such as working memory due to lack of manipulation and administration of memory and attention factors in control learning tasks. It would be more informative to understand the different stages and provide a plural view of SL to account for individual variability in SL performance.

6. Conclusion

Statistical Learning (SL) has emerged as a pivotal mechanism in cognitive and developmental science. SL's association with literacy, syntax comprehension, phonological and semantic access, word segmentation, and vocabulary has underscored its importance in language acquisition. For developmental disorders like DD and SLI, a link has been revealed between language deficiencies and SL deficits. Individuals with DD or SLI demonstrated poorer performance in SL tasks, emphasizing SL's significance in language impairments. However, the research on autistic groups revealed diverse findings. While some studies suggest intact SL ability in autism, others highlight differences, possibly tied to language impairments or socio-cognitive deficits. This variance across domains and within individuals with ASD complicates a definitive understanding of SL's role in this population.

The theoretical construct surrounding SL and its link to language impairments remains complex and elusive. While some studies suggest intact SL abilities in certain domains among autistic individuals, others propose atypical SL, attributing language impairments in ASD to distinct learning mechanisms. This disparity underscores the intricate nature of linguistic SL tasks, revealing domainspecific patterns and individual variations in cognitive performance. Besides, several unanswered questions persist in the construction of a whole framework. Challenges remain unsolved including the need for a well-structured theory that integrates empirical evidence, clarifies the nature of experimental SL tasks, and explains the underlying processes of pattern assimilation and learning. Future directions in SL research call for methodologies that mimic real learning processes, considering the intricacies of pattern assimilation and accompaniment by other cognitive faculties. In summary, while SL's role in language acquisition is evident, a comprehensive theory accounting for its complexities and relation to language impairments remains elusive. The intricate nature of its functioning demands a comprehensive theoretical framework and refined methodologies for a deeper understanding of its role in human cognition and development. The journey to unlocking the mysteries of SL and its implications for language acquisition and impairments remains an ongoing and evolving pursuit within the realm of cognitive science.

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