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Towards a New Taxonomy of Pattern-Making in the Visuo-Spatial Domain in Early Childhood Based on Zygonic Theory and the Sounds of Intent Framework of Musical Development

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Abstract

Pattern identification is an important part of children's development in understanding both music and mathematics. However, a review of the literature indicates that no formal taxonomy of pattern-making in the visual domain exists, which potentially limits practitioners' capacity to support children in improving their mathematical understanding. This paper seeks to redress this situation with a theoretical examination of whether visuo-spatial pattern-making in early childhood develops on the same trajectory as pattern-making in the auditory domain. The cognition of musical structure (which is based on repeating patterns) in childhood has been defined in zygonic theory and the subsequent Sounds of Intent framework. Prior observational studies of children with both neurotypical and non-typical development (i.e., Ockelford et al., 2011; Voyajolu, 2021) have confirmed this thinking. Drawing on the principles set out in zygonic theory and using the structure laid out in the Sounds of Intent framework, the researchers propose how to map the development of pattern understanding from the auditory domain onto the visuo-spatial domain. An algorithm is used to demonstrate the structural processing load for different pattern types, which allows the putative developmental stages of pattern-processing capacity to be plotted sequentially. As a future step, exploratory research with children is suggested to test these assumptions and further develop our understanding of the perception of patterns within and between the domains. It is anticipated that this work would support practitioners working with children to offer alternative strategies to support the development of pattern-making in mathematics.

Keywords

Auditory, early years, pattern-making, sounds of intent, taxonomy, visuo-spatial, zygonic theory

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Introduction

Patterns, of one form or another, underpin a wide range of human endeavors, from science and mathematics to art and music. Young children's pattern-making has recently been associated with their later mathematical understanding (Rittle-Johnson et al., 2017). This is thought to be driven by the identification of predictable structures based on a set of rules such as "repeating units" (Zippert et al., 2020). Children's musical understanding also stems from the recognition of patterns of increasing complexity (Ockelford, 2005). This parallel

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structure of understanding may conceivably present opportunities for children who struggle to conceive patterns visually to improve their mathematical understanding through musical pattern-making.

The purpose of this theoretically focused paper is therefore to explore how the developmental taxonomy of the cognition of musical structure, as defined by zygonic theory and set out in the Sounds of Intent framework (Ockelford, 2005; Ockelford & Voyajolu, 2020), may potentially inform our understanding of pattern-making[1] in the visuo-spatial domain in early childhood, and *vice versa*. This consideration will hopefully result in a fruitful cross-disciplinary fertilization of ideas and contribute to supporting children's mathematical learning in a novel way. Thus the paper will next explain zygonic theory and the Sounds of Intent framework, followed by a discussion of pattern-making in the auditory and visuo-spatial domains. The paper then proposes a model for exploratory analysis of whether pattern-making develops on the same trajectory in both domains.

Understanding Patterns in Music: Zygonic Theory and the Sounds of Intent Framework

Zygonic theory (Ockelford, 2009) holds that all musical structure is ultimately based on *repetition that is perceived to be intentional*, which is referred to as *imitation*. Imitation in music occurs at different levels, pertaining to *events* (notes), *groups* (melodic and rhythmic motifs) and *frameworks* (scales and meters). Further, the theory asserts that these levels make increasing cognitive demands and that they occur in a developmental sequence that is identifiable as children move through the early years. Individual differences and the environment in which children develop both have an impact on development. Therefore variability in rate of cognitive development is to be expected both between individuals and between groups of children growing up in different circumstances (Voyajolu, 2021).

Evidence of the existence of the sequence of music-developmental phases pertaining to different forms of musical structure, and of the varied rates with which the sequence manifests itself, comes from observational research across several studies (see Ockelford et al., 2005; Voyajolu & Ockelford, 2016; Welch et al., 2009). These bottom-up observational studies have been conducted in relation both to children developing at a normally-expected (neurotypical) rate (for example, Voyajolu, 2021) and to those growing up with non-neurotypical cognitive or perceptual conditions such as profound learning difficulties (Ockelford et al., 2011), autism (Shaughnessy, 2022), vision impairment (Voyajolu et al., 2023), and deafness and hearing loss (Ockelford & Marsden, 2021). Evidence from these studies shows that the phases of musical development:

i. only approximately correspond to age, even in neurotypical development, and
ii. build on one another but do not replace one another. (Voyajolu, 2021)

For example, mixed methods research (which incorporated qualitative analysis of children's musical development, quantitative conversion of qualitative analysis, and longitudinal case study research) conducted by Voyajolu (2021) examined the musical development of 44 "typically developing" children aged between 0–5 years of age via 796 naturalistic observations over a two-year period. Quantitative analysis of the level of children's musical development demonstrated that whilst musical development progressed with age, at each age there was a wide spread of musical capabilities (see Figure 1).

Additionally, analysis of the 796 observations also indicated that as higher levels of musical understanding were emerging, lower levels of musical development continued to be observed. Considering one of the case studies included in Voyajolu's research, we can see this illustrated in Figure 2. At 21 months, this participant displayed musical development at multiple different levels.

In addition, there is a "pre-auditory" phase of development, before hearing is initiated, typically observed in-utero, up to three months before birth. This phase is followed by a "pre-structural" or "sensory" phase, which emerges following birth to around nine months of age and is characterized by children hearing sounds or making sounds as a pure sensory experience. Awareness of the relationships between sound events is characterized by the third stage of development the "structural" phase. This phase extends to include an understanding of groups of sounds and then recognition of whole pieces of music. Later in development, in the teenage years, a "meta-structural" phase corresponding to "pragmatics" in language occurs, in which pieces of music are appreciated in their wider social and cultural contexts (Ockelford et al., 2011). Additional detail of the phases of development can be found in Table 1. The Sounds of Intent framework (Ockelford, 2015) was developed to support the application of zygonic theory into practice for people working with both neurotypical and non-neurotypical children. Developed via quantitative and qualitative research (see Cheng et al., 2009; Ockelford et al., 2005) the framework conceives of musical development as existing in six levels, typically occurring from 3 months before birth through to the teenage years following the stages outlined in Table 1.

Empirical studies designed to explore whether musical skills developed in children with learning difficulties using the Sounds of Intent framework offered a large amount of observational data to evidence this trajectory of development. For example, Ockelford and colleagues (2011) worked with 20 students with Profound and Multiple Learning Difficulties (PMLD) from age 11 to 17 years in a special school setting in London. Over a six-month period, researchers observed the musical behaviors of the participants in weekly music lessons of 45 min. Table 2 shows examples of the behaviors observed. These behaviors were

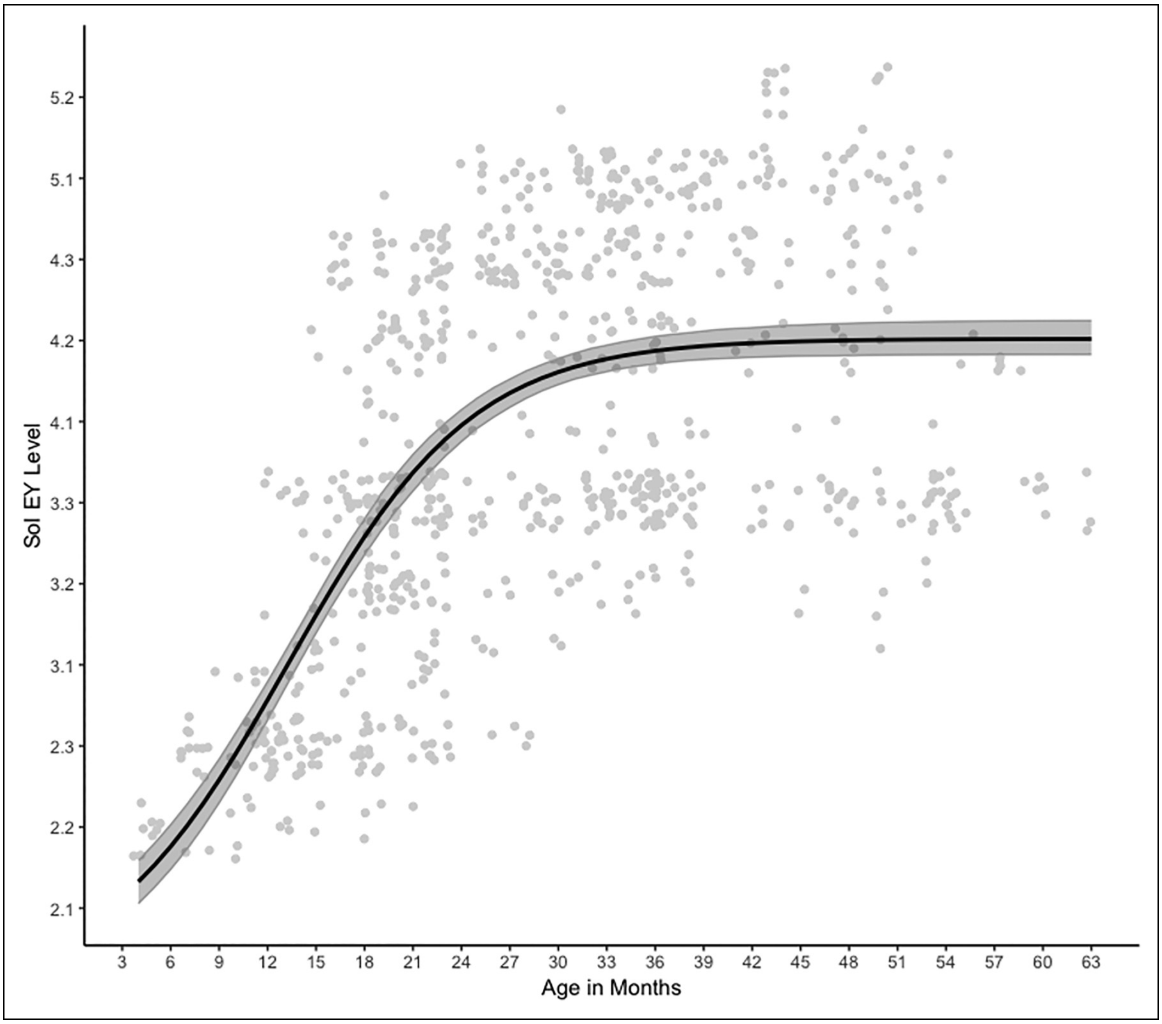


Figure 1. Scatterplot of N = 796 coded observations with growth curve and 95% CI.
Source: Voyajolu, 2021.

analyzed and categorized on the Sounds of Intent framework before being quantitively transposed to produce an understanding of children's musical development.

Similarly, Welch et al. (2009) conducted classroom-based music lesson observations with 68 participants (age 4 to 19 years) with PMLD in five special schools over a period of seven months providing analysis of 630 observations. Based on the wide range of behaviors and interactions observed during these empirical research projects and others (see Cheng et al., 2009 and Ockelford & Voyajolu, 2020), the framework recognizes three domains of engagement with musical sounds and music. These are "reactive" (listening and responding to sound and music), "proactive" (making sound and music alone), and "interactive" (making sound and music with others). Mapping the six levels onto the three domains yields 18 "headlines" of musical engagement, which are illustrated using concentric rings. See Figure 3.

In summary, in relation to pattern-making, the Sounds of Intent framework of musical development is founded on the notions that:

i. music comprises a range of patterns that, zygonic theory shows, are of differing complexity;
ii. these patterns make greater cognitive demands as they increase in complexity; and
iii. the capacity to grasp these patterns arises sequentially in cognitive development across the spectrum of neurodiversity, as the brain acquires more advanced processing abilities (as observed in Voyajolu, 2021 and detailed in Ockelford and Voyajolu, 2020).

Pattern-Making in the Visuo-Spatial Domain

Regarding pattern-making in the *visuo-spatial* domain, our starting point will be the taxonomy set out by Mulligan and Mitchelmore (2009) and Papic et al. (2011). Mulligan and Mitchelmore (2009, p. 34) posit the following:

> A mathematical *pattern* may be described as any predictable regularity, usually involving numerical, spatial or logical relationships. In early childhood, the patterns children experience

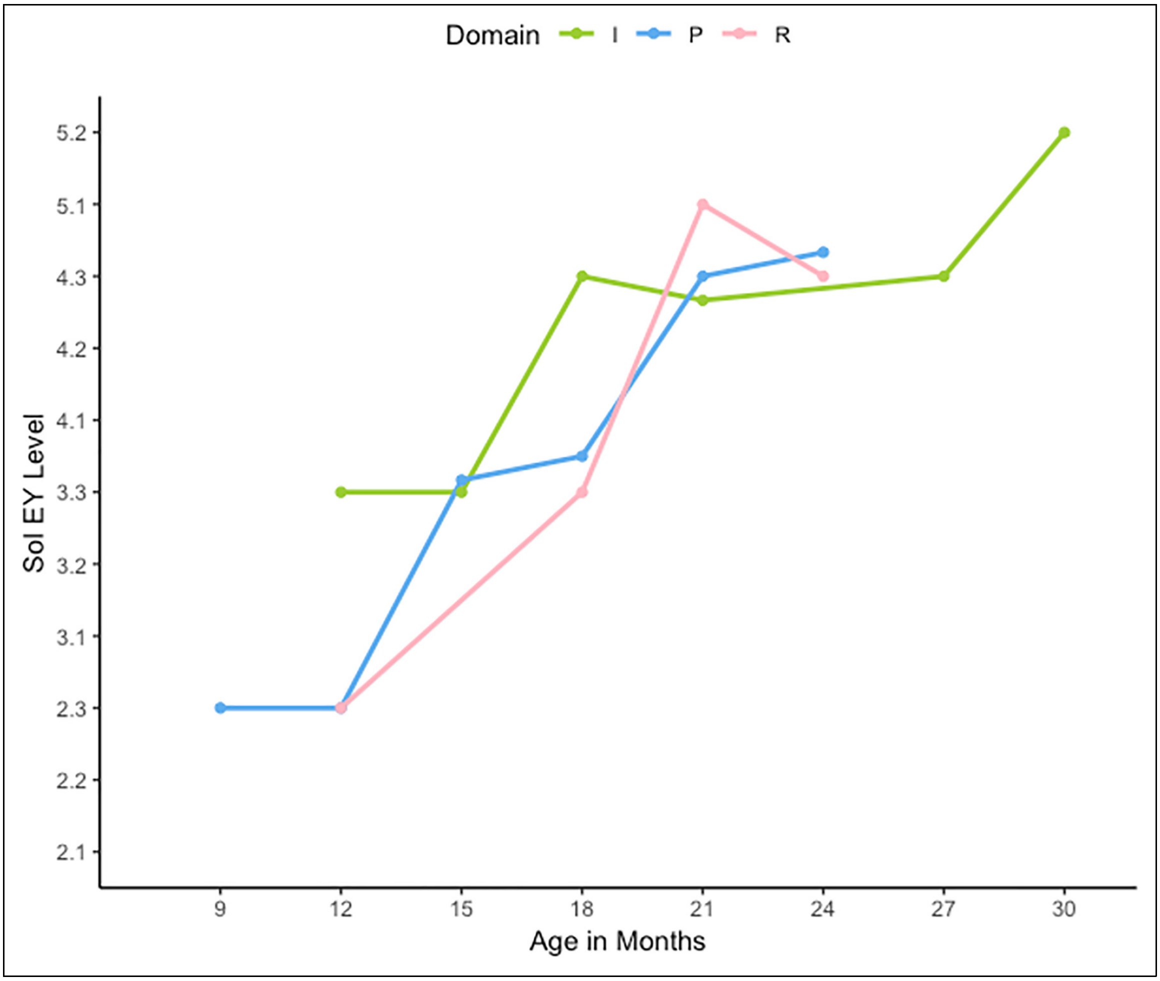


Figure 2. A child's average Sol-EY level over time per domain.
Source: Voyajolu, 2021.

include repeating patterns (e.g., ABABAB …), spatial structural patterns (e.g., various geometrical shapes) and growing patterns (e.g., 2, 4, 6, 8 …).

Mulligan and Mitchelmore assert that, in every pattern, "the various elements are organised in some regular fashion." In a later paper, Papic et al. (2011, p. 238 and 239) refer to these three manifestations of pattern as "contexts," which they consider to be of particular significance in mathematics. These may occur:

1. within a single object, in which some of its components are consistently related;
2. within an ordered set of objects, in which there is a consistent relation between each component and the next; and
3. between two ordered set[s] of objects, in which the corresponding elements are paired in some way.

The extent to which the capacity to grasp these patterns develops in children is not entirely clear: Following their experimental pattern intervention study with 53 children, Papic and colleagues note that "At a pre-school level, only the first two types [of contexts] are considered appropriate," though "In early childhood mathematics (i.e., up to Grade 2 [age 7 to 8 years]), children experience all three types of pattern" (2011, p. 239).

Based on this evidence it seems that Papic et al.'s classification derives from the observation of what young children typically experience at different stages in their education, with the inference that such experiences are developmentally apposite. Mulligan & Mitchelmore's (2009) research with 103 Grade 1 children [aged 6 to 7 years] went further, suggesting that development of pattern understanding could be categorized into four broad stages; pre-structural, emergent, partial structural, and structural. A fifth stage, advanced structural, was later added (Mulligan & Mitchelmore, 2013). These stages were defined by children's responses to 39 pattern and structure tasks, which were devised to demonstrate that a separate general construct of pattern and structure awareness exists within early mathematics understanding. The development stages were only researched with children aged 4, leaving a lack of understanding about how earlier and later pattern understanding develops. Therefore,

Table 1. The levels of musical development identified in the Sounds of Intent framework.

Stage of development	Level	Name	Structure pertaining to…	Description	Age range when this level usually predominates neurotypically	Typically associated level of disability
Pre-auditory	1	Learning to hear	–	Before hearing starts	Prior to three months before birth	Coma or vegetative state; the most profound learning difficulties
Pre-structural	2	Sounds interesting	–	Sound is heard or made as a purely sensory experience	From three months before birth to around nine months	Profound learning difficulties
Structural	3	Copy me, copy you	Events	Recognizing simple patterns, anticipating, and copying	From around nine months to around 15 months	Profound or severe learning difficulties; may include autism
	4	Bits of pieces	Groups	Hearing and creating groups of sounds as meaningful units of musical information, such as ringtones, motifs, and riffs	From around 15 months to around 33 months	Severe or moderate learning difficulties; may include autism
	5	Whole songs	Frameworks	Intuitively understanding simple musical structures; singing short songs in time and in tune; playing relatively simple pieces	From around 33 months onwards	
Meta-structural	6	The wider world of music	Events, Groups, and Frameworks understood in cultural contexts	Appreciating music in a mature way as a language of the emotions; performing persuasively within a familiar culture, potentially at an advanced level	In the teenage years	

Source: Ockelford et al., 2011.

within the existing literature there does not appear to be an overarching detailed theoretical framework, based on how an understanding of different types of patterns may be acquired across childhood development.

The Importance of Visuo-Spatial Patterns to Mathematics Understanding

The awareness of visuo-spatial patterns is critical to children's mathematical understanding and abilities (Kidd et al., 2014). Warren (2005) defines one goal of mathematics learning as being the ability to identify patterns, which allows children to deepen their mathematical skills. Research evidence has demonstrated the link between visual patterns and mathematics. For example, pattern understanding has been linked to children's grasp of calculation skills (Fyfe et al., 2017; Lüken & Kampmann (2018), numerical ability (Wijns et al., 2019), and algebraic thinking (Papic et al., 2011). Visuo-spatial patterning skills are malleable (Papic et al., 2011) and intervention studies have shown some causal effects of pattern training on children's mathematics outcomes, although larger studies are required (for a review see Burgoyne et al., 2017). Additionally, a longitudinal study of 500 children from low-income backgrounds showed that young children's patterning knowledge was more predictive

Table 2. Examples of observations recreated from Ockelford et al., 2011.

Observation
"J" showed slight reaction to loud noises but no reaction to localized instruments playing. Did not … change reaction to change in tempo/dynamics
"G" laughed each time the tambourine was hit, and responded to sudden chord changes
"A" vocalized throughout songs and changed notes with key change
"B" laughed at a particular motif played on the piano
"L" reacted to people playing matching sounds, eyes looking from one to the other
"D" listened to sounds made by other children, sometimes just looking, sometimes smiling, sometimes laughing

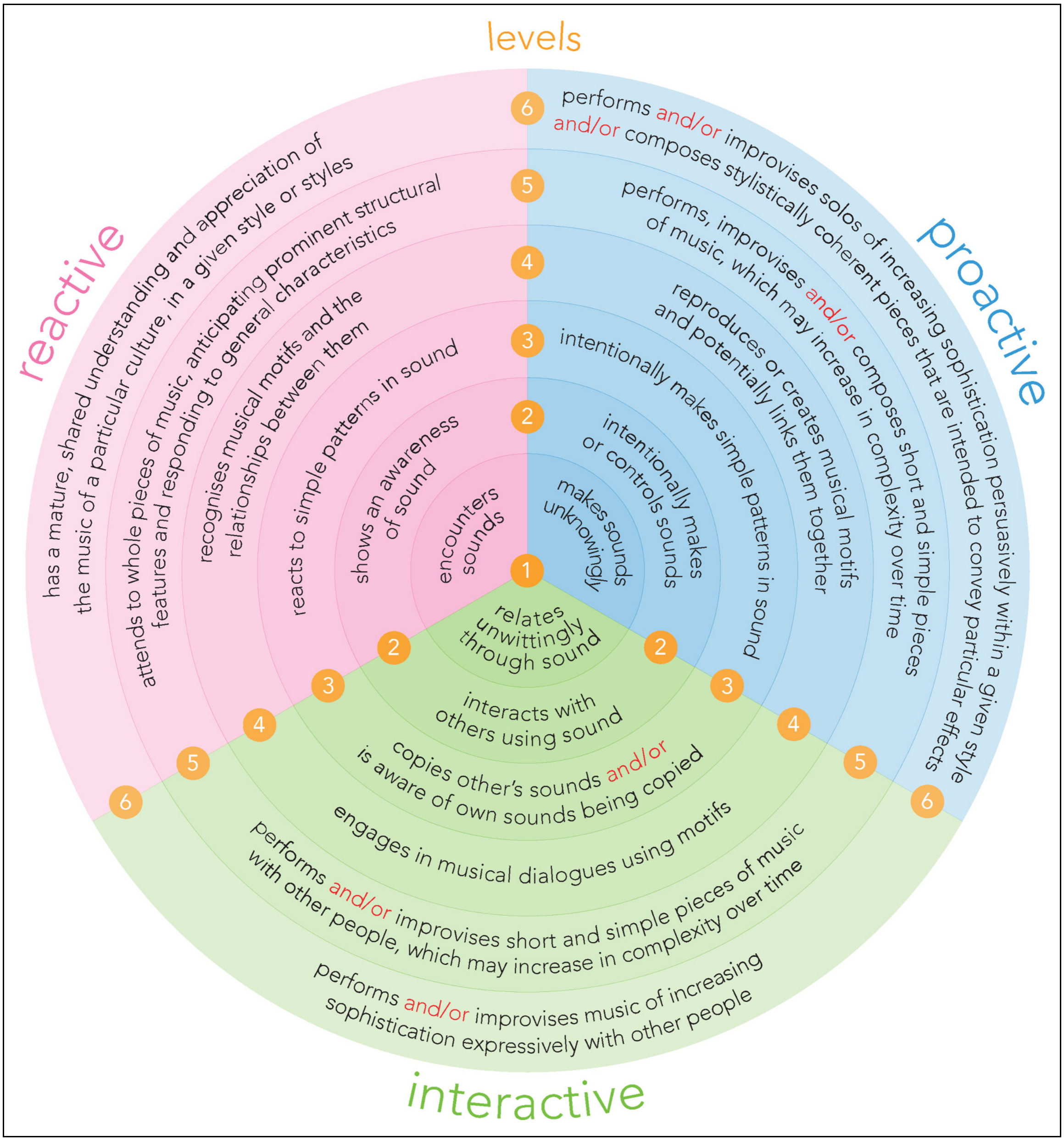


Figure 3. Visual representation of the sounds of intent framework.
Source: Ockelford et al., 2005.

Table 3. The proposed relationship between pattern, rules, and repetition, by domain.

	Auditory domain	Visuo-spatial domain
Pattern	Implies that a sound or a feature of a sound can be predicted in terms of *what*, *when*, and (in some cases) *where*.	Implies that an object or a feature of an object, or the visual representation of an object, can be predicted in terms of *what*, *where*, and (in some cases) *when*.
Rules	Such prediction occurs through the application of a rule.	All such rules are ultimately based on repetition.
Repetition	Repetition can relate to a note's perceived qualities in an "absolute" sense (e.g., pitch, timbre, loudness, duration) or in a "relative" sense, such as interval in pitch or time, or pertain to a note's function (e.g., tonic, subdominant, up-beat, down-beat).	Repetition can relate to an object's perceived qualities in an "absolute" sense (e.g., color, size, shape) or in a "relative" sense: e.g., position (gauged relative to other items) and orientation (e.g., "upside down") in space and/or time, ordinality ("second in line," "fourth in line," etc.) or pertain to an object's function (e.g., "item that can be worn on the foot" or "item that can be drunk from."

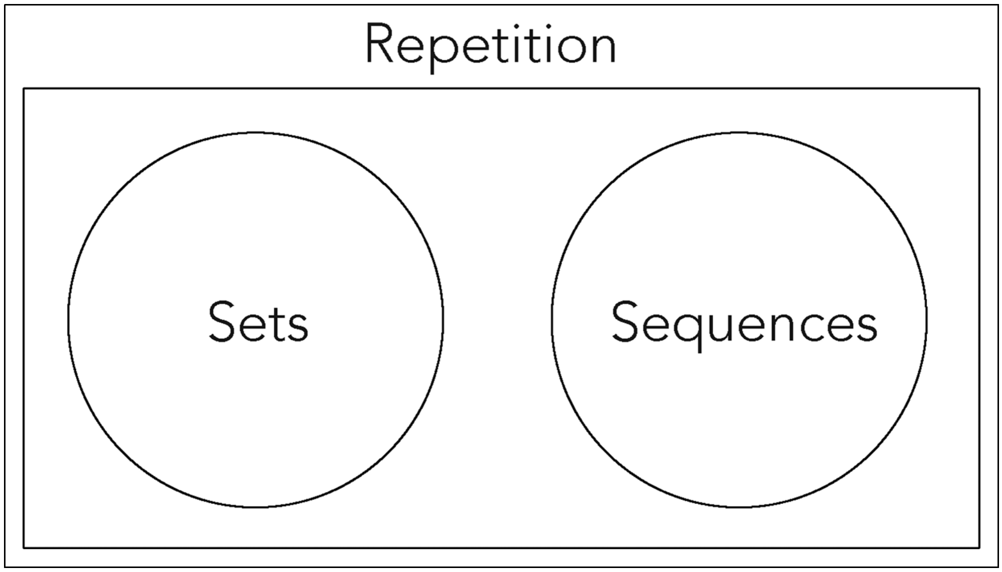


Figure 4. Repetition, sets, and sequences.

Table 4. Sets and sequences in the auditory and visuo-spatial domains.

	Example of set	Example of sequence
Auditory domain	Sounds made by a set of six percussion instruments	A regular beat on an instrument
Visuo-spatial domain	A bag of snooker balls	An equally spaced line of (red) snooker balls

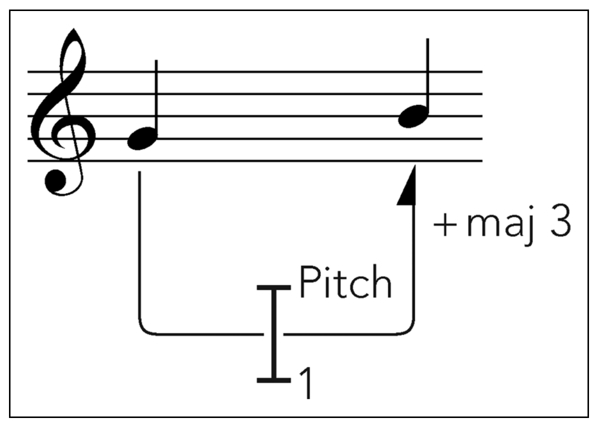


Figure 5. Example of relationship of pitch between two notes.

of later mathematical abilities aged 11 than number understanding (Rittle-Johnson et al., 2017). Therefore, developing a detailed understanding of how visuo-spatial patterns develop in early and later childhood could be a critical support to education practitioners in developing children's mathematics skills.

Given the development of the Sounds of Intent framework and the subsequent body of evidence supporting the theoretical assumptions of pattern development in the auditory domain, it seems logical to question whether this can be translated to visuo-spatial patterns. That is:

i. Can different visuo-spatial patterns be defined in terms of their complexity as we have seen in musical patterns?
ii. If so, do increasingly complex patterns make increasing cognitive demands?
iii. And, if so, does the capacity to grasp these patterns arise sequentially in cognitive development (for both neurotypical and non-neurotypical children), as the brain acquires more advanced processing abilities?

Complexity in Patterns

To explore the questions above theoretically, we need to consider the notion of complexity given our understanding from zygonic theory that our cognition of patterns moves from the simplest forms such as one repeating item (an "event" in Zygonic theory or a repeating "A" pattern in visuo-spatial patterns) to complex patterns such as different items repeating in a fixed order (i.e., "groups" in zygonic theory or "ABC, ABC, ABC" in visuo-spatial patterns). Complexity has been the subject of a wide range of psychological study, much of it rooted in Information Theory (Shannon & Weaver, 1949). Subsequently, researchers such as Attneave (1954), Hick (1952), Miller (1953), and Pollack (1952) used the concepts of entropy and redundancy, central to Information Theory, to address different issues in perception and cognition. Musicologists such as

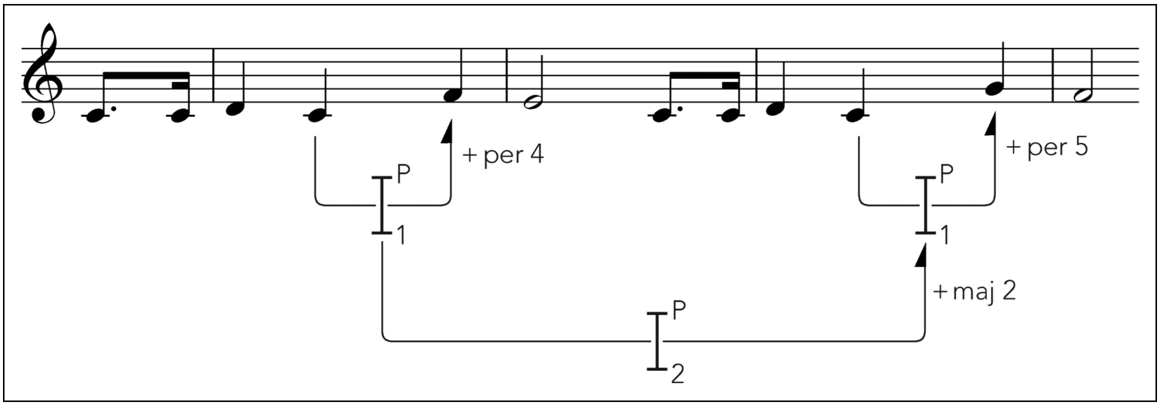


Figure 6. Example of secondary relationship of pitch in Happy Birthday.

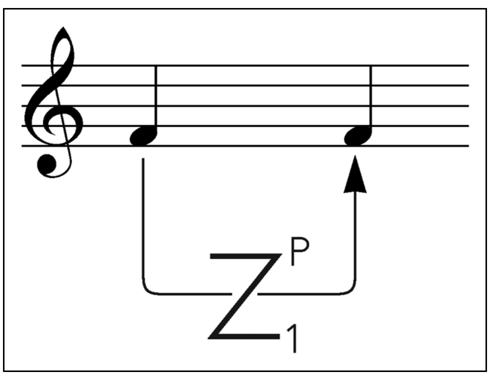


Figure 7. Primary zygonic relationship of pitch.

Meyer (1967) and Zuckerkandl (1969) and the psychologist Diana Deutsch (2019) adapted ideas from gestalt psychology to explain the cognition of music as the perception of complex patterns (sounds) that are assimilated as a unified whole (the music).

Theories of how complexity in understanding visuo-spatial patterns evolves in childhood include examples such as that developed by Muir et al. (1994, p.141), who state that "between 3 and 4 months of age, [babies] become sensitive to various types of static pattern regularities such as symmetry and other global configurational properties." That is, the recognition of patterns occurs very early, in line with our understanding of how auditory patterns develop (Voyajolu, 2021) Puspitawati (2011, p. 116) concludes that, in typically developing children, the understanding of pattern occurs first via local processing, with the emergence of global processing at four years of age, following which local-global processing integrates from around the age of five. One experiment involved children between the ages of three and nine. Puspitawati had them attempt to reproduce the outlines of large circles and squares formed of smaller circles and squares, with responses defined as "global," "integrated," or "local." The approach of differentiating between these "global" and "local" responses draws on gestalt psychology (Kimchi, 1992) echoing the direction taken by musicologists (see Deutsch, 2019). It is of interest to note that the way in which pattern perception develops in children is not universal; for example, children on the autism spectrum appear to have a processing bias towards local and featural information relative to a global understanding (so-called "weak central coherence" – see, for example, Happé & Frith, 2006).

These lines of research notwithstanding, there still appears to be a gap in our knowledge, in that there is no agreed developmental taxonomy of visual pattern perception based on complexity. Such a framework could support practitioners in extending all children's understanding of pattern. Given the importance of pattern understanding to mathematics performance (Lee et al., 2011; Rittle-Johnson et al., 2017), a development trajectory could be a useful tool in supporting mathematics skills development as the Sounds of Intent framework has supported musical development. Therefore, we are proposing to ascertain whether the principles of zygonic theory, developed in the context of auditory perception, may be applicable in the visual domain. What follows is a detailed discussion of how the fundamental principles of zygonic theory could be applied to establish a theoretical model of development in the visuo-spatial domain.

How Zygonic Theory Could be Applied to Evolve a Developmental Taxonomy for Understanding Visuo-Spatial Patterns

Preference Rules as a Starting Point

The zygonically-informed developmental taxonomy that exists in relation to music, is, as we have observed, somewhat "broad brush," pertaining to events, groups, and frameworks. It is known that these levels contain structural sub-categories (see Ockelford, 2002) that for the purposes of music-developmental assessment are not usually broken down further. However, in translating the Sounds of Intent taxonomy to a different domain, these levels provide more granular understanding that can shape our theorizing. This could potentially be achieved by adapting

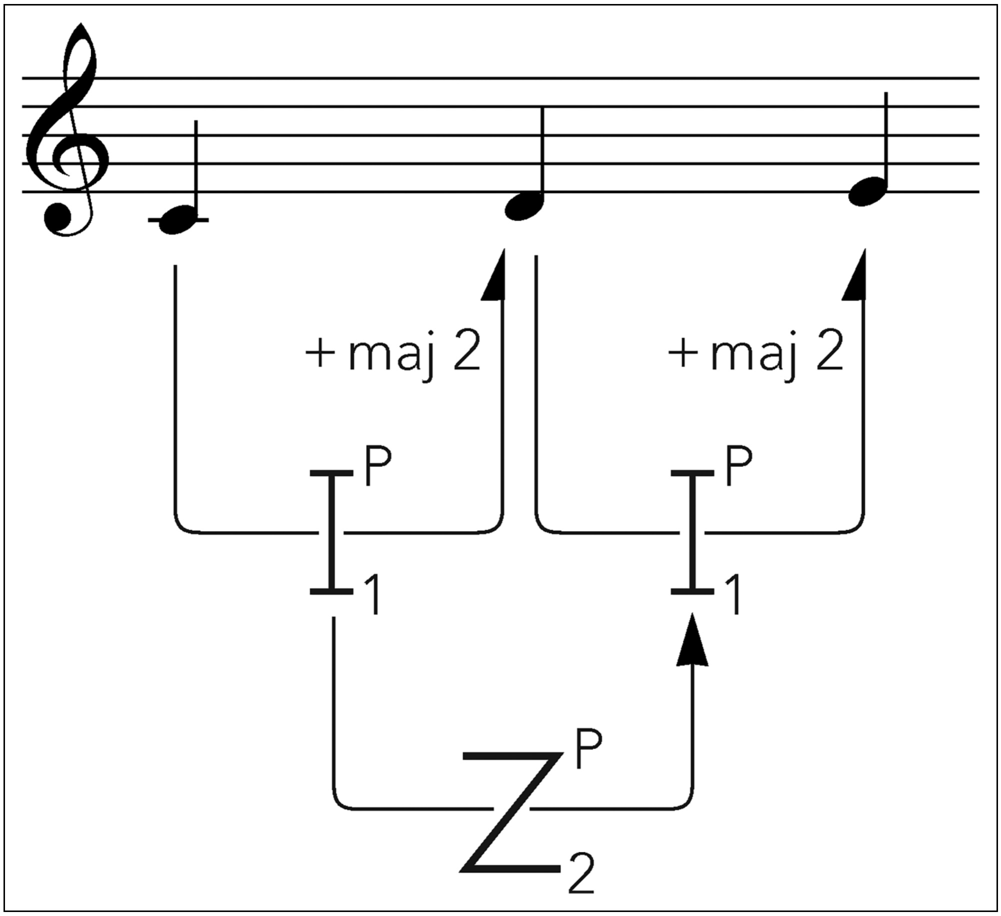


Figure 8. Secondary zygonic relationship of pitch.

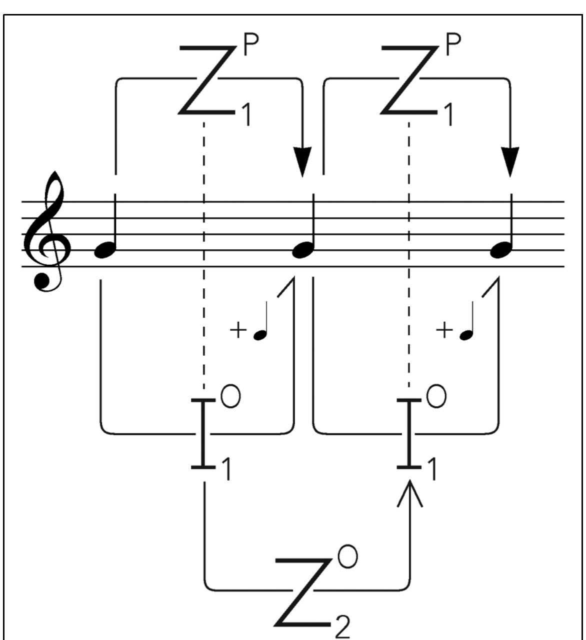


Figure 9. Primary zygonic relationships of pitch operating in parallel with a secondary zygonic relationship of onset.

the "preference rules" for music-structural cognition set out by Ockelford (2005, p. 125; see also Lerdahl & Jackendoff, 1983 and Huron, 2006). "Preference rules" were formulated pertaining to notes, groups, and frameworks, to try to understand which forms of musical structure the brain may attend to, given that music is imbued with many patterns that exist at the same time. Preference rules follow "Occam's razor" (Duignan, 2023) or the principle of parsimony – the notion that the mind searches for the simplest explanation of a phenomenon. In terms of musical structure, the preference rules set out in Ockelford (2005, p. 125) provide a theory for how the brain manages complexity in music:

i. lower levels of relationship are preferred to higher;
ii. fewer relationships are preferred to more;
iii. parallel relationships are preferred to non-parallel; and
iv. simpler functions are preferred to more complex (that require more transformational power).

Using these preference rules as the basis for an algorithm, it is possible to quantify structural complexity in music (see "Understanding Repetition, Pattern, and Structure across the Two Domains").

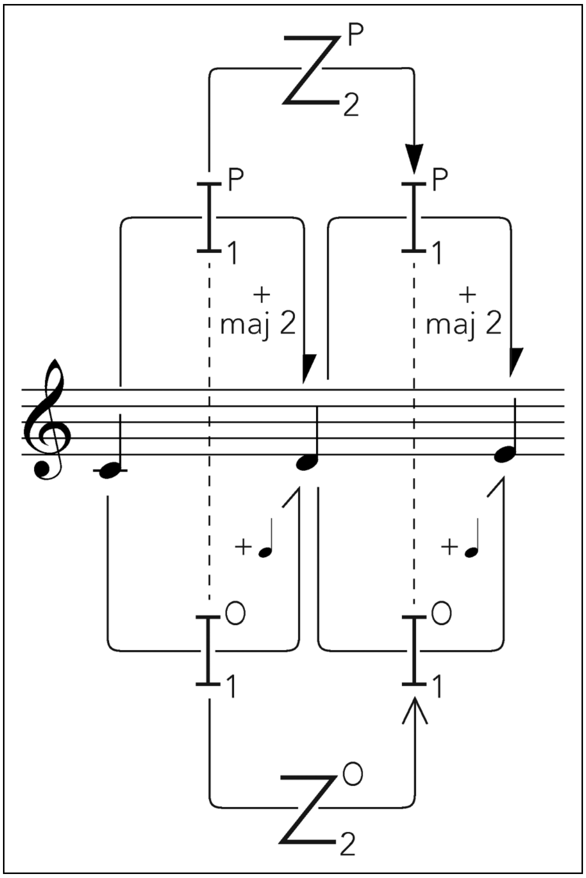


Figure 10. Secondary zygonic relationships of pitch and onset functioning in parallel.

Preference rules have also been considered in relation to complexity in visuo-spatial perception. Koffka's Law of Prägnanz states that in understanding complex visual patterns, our perception defaults to the most simple and stable shape (Koffka, 1935). This perceptual tendency drives us to experience things as regular, ordered, symmetrical, and in their simplest form. Given this, it is proposed that the principles for understanding music complexity could reasonably be adopted to derive perceived complexity scores for visuo-spatial patterns. This would allow for a taxonomy of pattern perception development in the visuo-spatial domain to be proposed, which could be empirically tested.

Understanding Repetition, Pattern, and Structure Across the Two Domains

Repetition is both *necessary* but not always *sufficient* to form pattern. Pattern implies the capacity for prediction and pertains to "when" and/or "where" and "what." For pattern to be perceived, repetition must be detected in relation to a *positional* parameter ("when" or "where") and a *feature* parameter ("what"). Prediction is based on rules that derive from repetition, pertaining to absolute or relative characteristics of a visual or auditory object, or to their perceived function (see Table 3).

However, as we have seen, not all repetition forms pattern, since repetition does not necessarily lead to predictability. This is because repetition can form both (unordered) "sets" and "sequences" (see Figure 4).

Examples of sets and sequences in the auditory and visuo-spatial domains are set out in Table 4.

It is helpful to define the cognition (and creation) of sets and sequences in terms of zygonic theory. Whilst zygonic theory was conceived in relation to music, it has been extended to other domains (Ockelford, 2020). Particularly relevant here is the one pertaining to art (Cooper, 2016), which adopts the same line of thinking.

As we have seen, zygonic theory concerns relationships between musical events (typically, notes). Relationships can exist between any qualities of a note, such as its pitch, timbre, loudness, or duration (see Table 3). They can be represented as per Figure 5, where the "I" stands for interval.

These are termed "primary" relationships (shown by the lower suffix "1"), because they exist between the qualities of sounds themselves. It is further possible that the brain perceives connections between these (primary) relationships – one step further abstracted from the perceptual surface – and these are termed "secondary." For example, the difference between one pitch and the next may be a "perfect fourth," and the difference between a third pitch and a fourth may be a "perfect fifth." This happens in the first two lines of *Happy Birthday*. The ear hears (typically non-consciously) the first interval as being larger than the second (in music theory, it is greater by a "major second"). The *level* of relationships – whether they are primary and secondary – is, again, shown with subscripts. The superscript "P" shows they are relationships of *p*itch (see Figure 6).

It may be that one quality of a note (or more than one) is the same as that (or those) of another, and that this repetition is perceived to be intentional (occurring through human agency). Intentional repetition constitutes *imitation.* In this case, the relationship of identity between them is said to be "zygonic" (from the Greek "zygon," meaning the union of two similar things). Primary zygons, illustrated in Figure 7, underpin one of the commonest forms of musical structure, when one element or feature of music is heard to imitate another.

Secondary zygons, involving imitation relating to the differences between notes (or "intervals"), are ubiquitous too. Consider, for example, the first three notes of the children's song *Frère Jacques*. The zygonic hypothesis suggests that the brain calculates the pitch by holding the difference between the Notes 1 and 2 in working memory and recalling that difference to jump off from Note 2 and reach Note 3, a process that, again, typically occurs non-consciously. See Figure 8.

Pitch is one of the two key structural features of all music, the other being the organization of sounds in time.

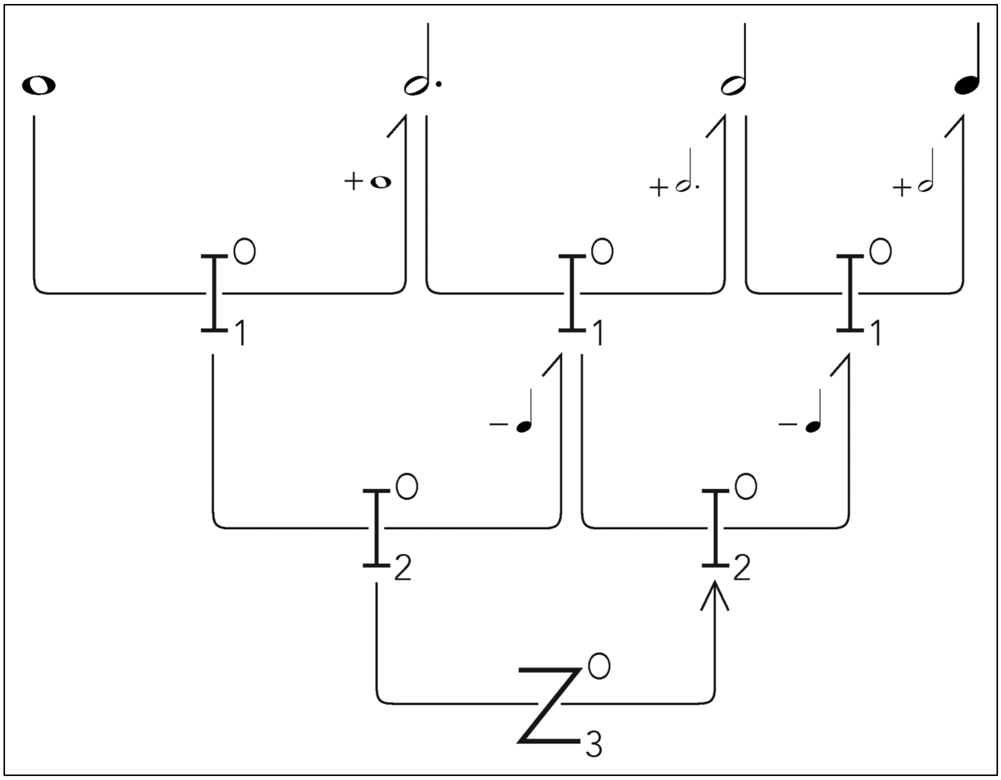


Figure 11. Tertiary zygonic relationship of onset.

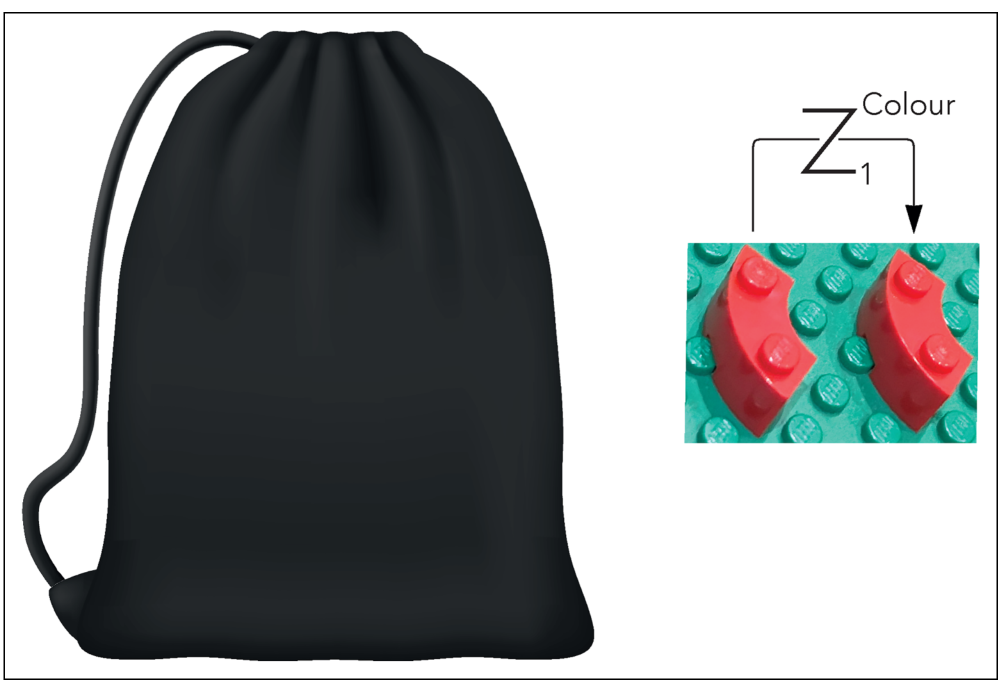


Figure 12. Primary zygonic imitation in the domain of color.

In this respect, the *onsets* of notes are particularly important: that is, the points in time when they start. Together, pitch and onset provide listeners with the *what* and *when* of the elements of music, which, as we have seen, are sufficient to construct patterns (see Table 3). Given that time is a purely relative phenomenon (unlike pitch, which has an absolute, stand-alone quality), its perceptual foundation exists at the level of primary relationships.

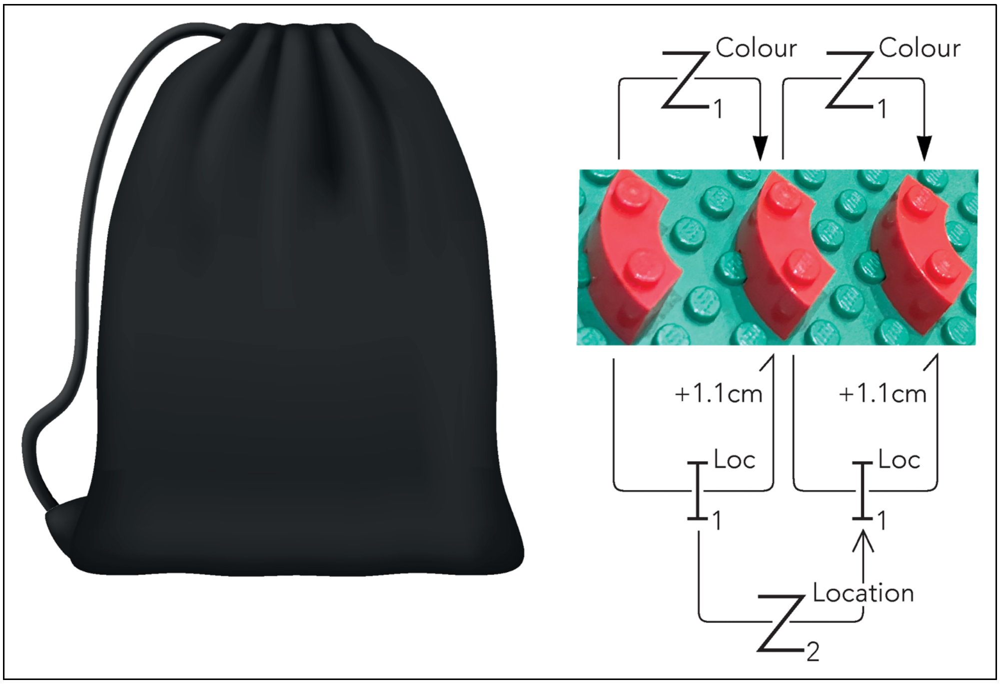


Figure 13. A pattern formed from three equally spaced bricks of the same color.

Hence the simplest (least abstract) form of structure in the temporal domain is a secondary zygonic relationship of onset. Consider the opening of the French folk song *Au Clair de la Lune*, which begins with three repeated notes that are equally spaced in time. Zygonic theory holds that a primary zygonic relationship of pitch and a secondary zygonic relationship of onset (shown with the upper suffix "O") occur in parallel, enabling listeners to recognize the pattern and singers to recreate the second and third notes in terms of pitch, and the onset of the third note. (See Figure 9.)

The first three notes of *Au Clair de la Lune* constitute an example of the simplest form of pattern that exists in music. Primary imitation in the domain of pitch provides the *what* of the pattern, and secondary imitation in the domain of time (between onsets) yields the *when*. Three notes are required to create a pattern (rather than two), because of the need for secondary imitation. The first two notes alone provide us with the simplest example of musical *structure*, but not yet a pattern, as defined here, through predictability.

Au Clair de la Lune provides us with an example of primary and secondary zygonic relationships working in parallel. Parallel secondary relationships in the domains of pitch and perceived time are ubiquitous too. Consider *Frère Jacques* again. The distance in time (or "inter-onset interval") between Notes 1 and 2 can be used to predict when Note 3 will occur, as shown in Figure 10.

Note that a notion of pitch in the absence of time exists in an abstract sense in the brain – recognition of the intervals between pitches is fundamental to much music perception. This occurs when the pitches used in a particular key in tonal music form an unordered set in memory and underpin *tonality*, which is both a framework of pitch and of pitch function (the role that each pitch is felt to play in relation to others, derived through statistical learning).

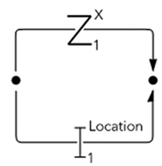
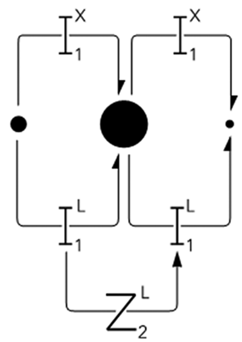
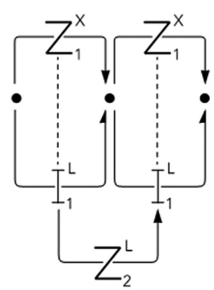
Tertiary zygonic relationships (see Figure 11) are a feature of music too (Ockelford, 2002). These occur when a series of musical sounds (e.g., bangs on a drum) get faster (or slower). Here, we have the repetition of regular change.

As we identified above, a key question to address is whether this thinking reads across to the visuo-spatial domain, and, if so, to what extent?

To set the scene, instead of notes, consider, once more, a bag of children's toy building bricks (Table 4). A child pulls a red brick out of the bag and puts it on a board. The child then deliberately picks out another red brick, as they want the second brick to be the same as the first. Looking at the two, next to each other on the board, it appears that the color of the second imitates that of the first, and therefore we can say that there is a primary zygonic relationship of color between them for both the creator and any perceiver of the child's action. (Note that there is imitation of other features too, such as shape.) (See Figure 12.)

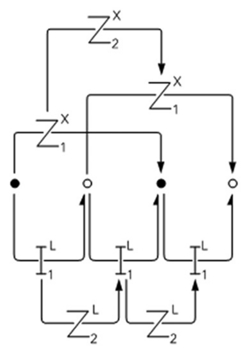
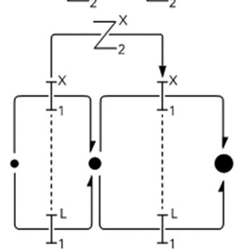
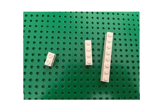
However, looking at the bricks on the board, according to the definition above, this is not yet a pattern, as that requires predictability. (What the child has done is akin to a sorting task.) The *predictability* pertaining to the arrangement of building bricks on the board concerns *where* (not when) – see Table 3. The *where* of the bricks is a purely relative thing, expressible as the distance between them on the board.

Table 5. Sounds of Intent framework level 3 incorporating auditory and visuo-spatial development.

Sub-level	Description	Underlying structure	Schematic representation	Structural Processing Load	Reactive, Proactive, Interactive	Examples: Auditory	Examples: Visuo-spatial	Pictures of activities
3(a)	Repetition of an item or a salient feature of an item	*Single primary zygonic relationship(s) relating to a feature (or features) of an item* STRUCTURE BUT NOT YET PATTERN		$SPL(X) = Z_{\#} \cdot \#D^{O} = 1 \cdot 1 = 1$ $SPL(L) = Z_{\#} \cdot \#D^{PR} = 0 \cdot 1 = 0$ $\mathbf{SPL(X + L) = 1}$	Reactive	Recognizes the repetition of a sound	Recognizes that two items are matched	
					Proactive	Repeats a vocal sound made by self	Matches one item with another from a varied selection	
					Interactive	Copies sound made by other, or encourages copying of self by someone else	Plays matching games with someone else	
3(b)	Repetition of the *when* or *where* of items, but not of the items themselves	*Secondary zygonic relationship(s) of onset or location* STRUCTURE BUT NOT YET PATTERN		$SPL(X) = Z_{\#} \cdot \#D^{O} = 0 \cdot 3 = 0$ $SPL(L) = Z_{\#} \cdot \#D^{PR} = 2 \cdot 1 = 2$ $\mathbf{SPL(X + L) = 2}$	Reactive	Recognizes that different sounds are regularly spaced in time	Recognizes that there are different items equally spaced	
					Proactive	Bangs a regular beat using different objects	Lines up objects, more or less equally spaced, but with no account of their features	
					Interactive	Copies someone else's regular beat using different objects	Plays interactive games where the position of objects is copied, but not the objects (or the qualities of the objects) themselves	
3(c)	Repetition of items, equally spaced in time or place	*Primary zygonic relationships pertaining to a feature or features working in parallel with secondary zygonic relationships of location in time or space* SIMPLEST FORM OF PATTERN		$SPL(X) = Z_{\#} \cdot \#D^{O} = 1 \cdot 1 = 1$ $SPL(L) = Z_{\#} \cdot \#D^{PR} = 2 \cdot 1 = 2$ $\mathbf{SPL(X + L) = 3}$	Reactive	Recognizes the repetition of a sound at a regular time interval	Recognizes that there are three or more items are the same and equally spaced	
					Proactive	Repeats vocal sound made by self or repeats a note on a keyboard, for example, to a regular beat	Lines up objects the same (from a choice) – equally spaced in one dimension	
					Interactive	Copies repeated sounds, equally spaced in time, made by someone else	Plays games copying equally spaced objects (that are the same, from a choice of different ones) arranged by someone else	

(continued)

Table 5. (continued)

Sub-level	Description	Underlying structure	Schematic representation	Structural Processing Load	Reactive, Proactive, Interactive	Examples: Auditory	Examples: Visuo-spatial	Pictures of activities
3(d)	Alternating items or events, regularly spaced	*Two separate series of primary zygonic relationships pertaining to a feature or features working in parallel with secondary zygonic relationships of location*		$SPL(X) = Z_{\#} \cdot \#D^{O}$ $= 2 \cdot 2 = 4$ $SPL(L) = Z_{\#} \cdot \#D^{PR}$ $= 2 \cdot 1 = 2$ **$SPL(X + L) = 6$**	Reactive	Recognizes that two sounds alternate and are regularly spaced	Recognizes that two items are alternating and are equally spaced	
					Proactive	Hums or plays patterns of two alternating sounds	Arranges a line of objects that alternates	
					Interactive	Copies alternating patterns of sounds made by another (or enjoys being copied)	Plays "alternating games" (taking it in turns to add an object, or copying an alternating pattern)	
3(e)	Regular change in items or events, not equally spaced in time or space	*Secondary zygonic relationships pertaining to a feature or features*		$SPL(X) = Z_{\#} \cdot \#D^{O}$ $= 2 \cdot 3 = 6$ $SPL(L) = Z_{\#} \cdot \#D^{PR}$ $= 0 \cdot 2 = 0$ **$SPL(X + L) = 6$**	Reactive	Recognizes regular change in a series of sounds, not equally spaced in time	Recognizes items are subject to regular change, but not equally spaced.	
					Proactive	Makes sounds that relate to each other through regular change (e.g., louder or quieter), but are not equally spaced in time	Lines up objects with regular change (e.g., size) – not equally spaced	
					Interactive	Copies sounds that change in a regular fashion, not equally spaced in time, made by someone else	Plays games copying objects (that different in a regular fashion, from a choice of different ones) arranged by someone else	

(continued)

Table 5. (continued)

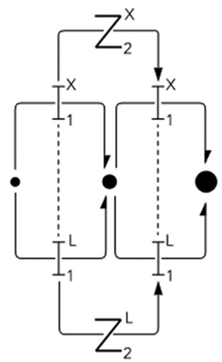
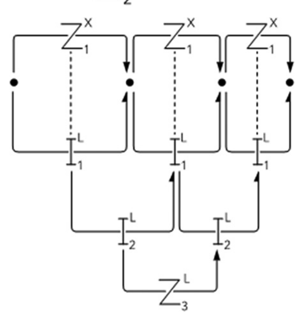
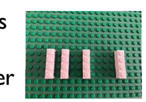
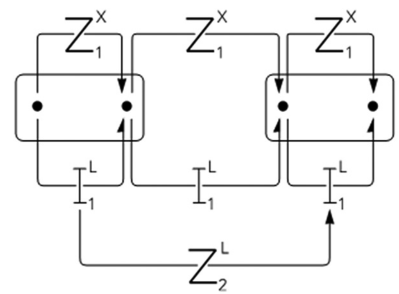
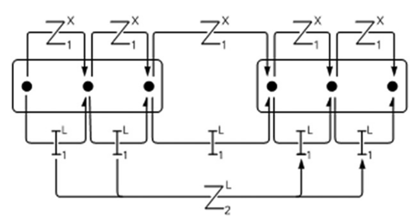
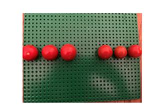
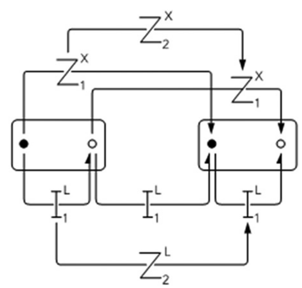
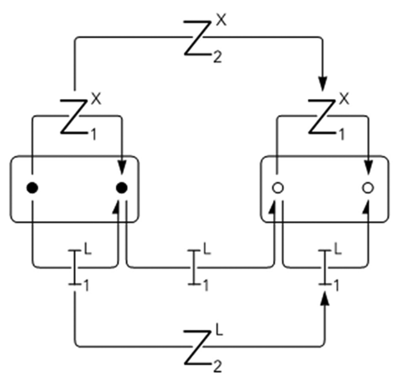
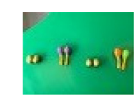
Sub-level	Description	Underlying structure	Schematic representation	Structural Processing Load	Reactive, Proactive, Interactive	Examples: Auditory	Examples: Visuo-spatial	Pictures of activities
3(f)	Regular change in items or events that are equally spaced in time or space	*Secondary zygonic relationships pertaining to a feature or features working in parallel with secondary zygonic relationships of location*		$SPL(X) = Z_{\#} \cdot \#D^{O} = 2 \cdot 3 = 6$ $SPL(L) = Z_{\#} \cdot \#D^{PR} = 2 \cdot 1 = 2$ $\mathbf{SPL(X + L) = 8}$	Reactive	Recognizes regular change in sounds regularly spaced	Recognizes items are changing regularly in relation to one another and are equally spaced	
					Proactive	Makes sounds that increase in volume and are regularly spaced	Lines up objects with a regular change (e.g., size), equally spaced	
					Interactive	Copies a pattern of sounds subject to regular change made by another (or recognizes when own patterns of this this kind are being copied)	Plays "copying game" in which a series of equally spaced items are subject to regular change	
3(g)	Variation of regularity in relation to time or place	*Structure created through the operation of a tertiary zygon of location*		$SPL(X) = Z_{\#} \cdot \#D^{O} = 1 \cdot 1 = 1$ $SPL(L) = Z_{\#} \cdot \#D^{PR} = 3 \cdot 3 = 9$ $\mathbf{SPL(X + L) = 10}$	Reactive	Recognizes that a series of sounds that are the same get faster or slower in a regular way	Recognizes that a series of objects that are the same get closer together or further away from each other in a regular way	
					Proactive	Makes a pattern of single sounds that change regularly in speed	Makes a pattern in which objects get closer together or further apart in a regular way	
					Interactive	Copies a regular change in speed	Copies patterns in which objects get closer together or further apart in a regular way, or recognizes own such patterns being copied	

Table 6. Sounds of Intent framework level 4 incorporating auditory and visuo-spatial development.

Sub-level	Description	Underlying structure	Schematic representation	Structural Processing Load	Reactive, Proactive, Interactive	Examples: Auditory	Examples: Visuo-spatial	
4(a)	Repetition of a series of two items or events that are the same	*Series of primary zygonic relationships relating to a feature (or features) of the items or events*		$SPL(X) = Z_{\#} \cdot \#D^{O} = 1 \cdot 1 = 1$ $SPL(L) = Z_{\#} \cdot \#D^{PR} = 2 \cdot 2 = 4$ $\mathbf{SPL(X + L) = 5}$	Reactive	Recognizes the repetition of a group of two notes that are the same	Recognizes two identical groups of items that are the same	
					Proactive	Repeats a group of notes that are the same	Matches a set of two items that are the same with another set from a varied selection	
					Interactive	Copies a group of two notes that are the same made by someone else, or recognizes own pattern of two notes that are the same being copied	Plays matching games of sets of two items that are the same with someone else	
4(b)	Repetition of a small group of the same items or events with the same spacing between them	*Set of primary zygonic relationships relating to a feature (or features) of the items*		$SPL(X) = Z_{\#} \cdot \#D^{O} = 1 \cdot 1 = 1$ $SPL(L) = Z_{\#} \cdot \#D^{PR} = 2 \cdot 2 = 4$ $\mathbf{SPL(X + L) = 5}$	Reactive	Recognizes repetition of a series of three identical notes that are equally spaced	Recognizes repetition of three identical items that are equally spaced	
					Proactive	Repeats a series of three notes that are the same	Matches a set of three items that are the same with another set from a varied selection	
					Interactive	Copies three notes that are the same made by another, or recognizes own pattern of three notes the same being copied	Plays matching games of sets of three identical items with someone else	

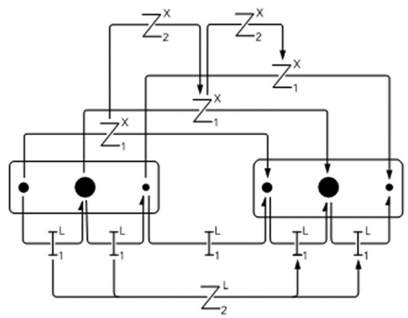
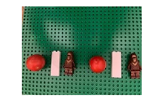
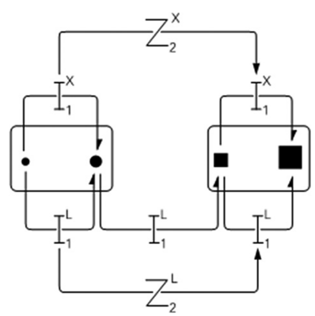
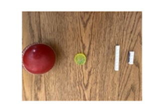
(continued)

Table 6. (continued)

Sub-level	Description	Underlying structure	Schematic representation	Structural Processing Load	Reactive, Proactive, Interactive	Examples: Auditory	Examples: Visuo-spatial	
4(c)	Repetition of short sequence of items or events; order of appearance maintained, but not precise relative location (in time or space)	*Series of parallel primary zygonic relationships relating to a feature (or features) of the items concerned*		$SPL(X) = Z_{\#} \bullet \#D^{O} = 2 \bullet 2 = 4$ $SPL(L) = Z_{\#} \bullet \#D^{PR} = 2 \bullet 2 = 4$ $\mathbf{SPL(X + L) = 8}$	Reactive	Recognizes a group of two different sounds being repeated	Recognizes series of two different items being repeated	
					Proactive	Repeats two different sounds made by singing or playing (e.g., chime bars, keyboard)	Repeats series of two items	
					Interactive	Copies pairs of different sounds made by someone else, or appreciates pairs of different sounds being copied by another person	Plays matching games with pairs of (different) items	
4(d)	Repetition of locations of short series of items or events	*Parallel secondary zygonic relationships pertaining to a feature (or features) and location in time or space*		$SPL(X) = Z_{\#} \bullet \#D^{O} = 2 \bullet 2 = 4$ $SPL(L) = Z_{\#} \bullet \#D^{PR} = 2 \bullet 2 = 4$ $\mathbf{SPL(X + L) = 8}$	Reactive	Recognizes the very repetition of pairs of sounds	Recognizes small groups of different items	
					Proactive	Creates two pairs of sounds that repeat, but differ from one another	Creates pairs of items that are the same, but that differ from one another	
					Interactive	Plays "call and response" games uses pairs of sounds that are the same, but that different from one another	Matches pairs of objects that are the same, but where the pairs differ from one another	

(continued)

Table 6. (continued)

Sub-level	Description	Underlying structure	Schematic representation	Structural Processing Load	Reactive, Proactive, Interactive	Examples: Auditory	Examples: Visuo-spatial	
4(e)	Repetition of a set of different items equally spaced	*Series of secondary zygonic relationships linking a series of features that are the same, which are themselves linked through secondary zygonic relationships, functioning together with a series of secondary zygonic relationships of location*		$SPL(X) = Z_{\#} \cdot \#D^{O} = 2 \cdot 3 = 6$ $SPL(L) = Z_{\#} \cdot \#D^{PR} = 2 \cdot 2 = 4$ **SPL(X + L) = 10**	Reactive	Recognizes that one series of different sounds that are equally spaced is the same as another	Recognizes that one series of different items that are equally spaced is the same as another	
					Proactive	Creates two identical series of different sounds that are equally spaced	Creates two identical series of different items that are equally spaced	
					Interactive	Imitates a series of different sounds that are equally spaced made by another person, or creates a series of such sounds for them to imitate	Imitates a series of different items that are equally spaced made by another person, or creates a series of such items for them to imitate	
4(f)	Repetition of locations of a small group of items that have the same internal difference	*Parallel secondary zygonic relationships pertaining to the difference between two features and location in time or space*		$SPL(X) = Z_{\#} \cdot \#D^{O} = 2 \cdot 4 = 8$ $SPL(L) = Z_{\#} \cdot \#D^{PR} = 2 \cdot 2 = 4$ **SPL(X + L) = 12**	Reactive	Recognizes that the difference within one pair of sounds is imitated in another pair (that is different)	Recognizes that the difference between one pair of items is imitated in another pair	
					Proactive	Repeats the difference between one pair of sounds in another (that is different)	Repeats the difference between one pair of items in another (that is different)	
					Interactive	Engages in call and response activities in which the difference between one pair of sounds is the same as that in another (that is different)	Engages in activities with another person in which the difference between one pair of items is the same as that in another (that is different)	

To create a pattern – the simplest of patterns in the visuo-spatial domain – the child picks out a third red brick and places it equally spaced from the second, as the second is from the first. This can be said to occur through a secondary zygonic relationship of location (see Figure 13).

This example suggests, at least in relation to a simple set of circumstances, that there is a read-across from pattern in the auditory domain to pattern in the visuo-spatial domain.

Mapping and Matching Structure and Patterns in the Auditory and Visuo-Spatial Domains Using Zygonic Theory and the Sounds of Intent Framework

In applying this idea – that there is an equivalent structure and patterns across the auditory and visuo-spatial domains – Tables 5 and 6 below suggest mapping of the developmental steps at the structural levels of the Sounds of Intent framework to the visuo-spatial domain (see Table 1). To ensure structures or patterns of equivalent complexity are selected in each of the two domains, each level is sub-divided according to a new measure, termed the "structural processing load" (SPL) of each form of structure or pattern. The SPL is an algorithm which allows an unbiased assessment of the level of complexity within each pattern type. This method provides a rigorous approach to determine how patterns that we see equate to patterns that we can hear in terms of how hard it is for the brain to make sense of them.

SPL has two elements: the first relates to the parameter (or parameters) in question that relate to the *quality* or *qualities* of an event or item (such as color, timbre, pitch, or shape) – in general terms: "SPL(X)." The second relates to the *location* of the event or item (in space or time) – in general terms: SPL(L).

SPL(X) is calculated as follows. There are two parameters at play: the highest level of structural (zygonic) relationship that is operating (symbolized by "$Z_{\#}$") and the number of different objects (items or events ("$\#D^{O}$").

Increasing either $Z_{\#}$ or $\#D^{O}$ increases the structural processing load, and when $Z_{\#} = 0$, SPL = 0. These two requirements mean that SPL(X) should be expressed a product:

$$SPL(X) = Z_{\#} \bullet \#D^{O}$$

SPL(L) is calculated along similar lines, considering that location in time or space is invariably *relative*. Hence, the algorithm takes into accounts the number of *primary relationships* that exist:

$$SPL(L) = Z_{\#} \bullet \#D^{PR}$$

SPL(X) and SPL(L) do not directly interact with each other. Hence the total SPL can be regarded as the sum of the two. That is,

$$SPL = SPL(X) + SPL(L)$$

Tables 5 and 6 detail examples of how each sub-level in the framework can be explored with children. These examples offer activities in each domain of engagement: reactive, proactive, and interactive.

In practice this might work as follows. Let us consider sub-level 3(b) in Table 5. As part of an interaction with another person, a child can be judged to have understood a secondary zygonic relationship in a pattern in the auditory domain if they can copy different sounds that are regularly spaced in time. In the visuo-spatial domain, if a child can copy a pattern in which different items are regularly spaced from one another, they, too, can be judged to have understood this simple pattern.

Moving to more complex patterns in Table 6, if a child can repeat a pattern in which there are two different sounds equally spaced and recurring, they have understood a pattern at level 4(d). The equivalent pattern in the visuo-spatial domain would be a pattern involving two different objects that repeat (an AB, AB, AB pattern).

Conclusion and Next Steps

Establishing the path of development for pattern-making in the visuo-spatial domain extends our understanding of how pattern perception across different domains develops in young children. Such work would allow parallels to be drawn between the visuo-spatial domain and the auditory domain in the first instance and permit researchers to explore how learning can be transferred between these domains. Examination of the development of how patterns are understood in these domains may also offer researchers and practitioners insights into the functioning of working memory and other areas of executive function, which could be incorporated into programs to support children's learning.

A suggested way forward is to conduct an exploratory study utilizing appropriate activities from the extended Sounds of Intent framework detailed in Table 5 and 6. Participants could include children with cognitive and perceptual conditions who need additional support in developing mathematics skills. Children who are non-verbal could also benefit from alternative strategies for demonstrating their understanding of mathematical and musical concepts through patterning rather than verbalization. The proposed framework could be used to identify a baseline for each participant in the auditory and visuo-spatial domains. The suggested activities could then be used, over a series of weeks, to explore how cognition in both domains develops. An empirical study such as that suggested would provide researchers with the opportunity to test the assumptions made in the theoretical framework. Practical implementation of the framework would also allow differences between pattern comprehension in each domain to be understood. For example, physically placing objects in visuo-spatial patterns (i.e., colored wooden blocks) may require a greater understanding than making vocal sounds in the same pattern structure. Some aspects of pattern-making may also be mechanical (i.e., repeating hand claps) which would be useful to identify in understanding how pattern perception develops. Ultimately the aim of future research should be to enable practitioners working with children with neurodevelopmental delays to draw on a range of inclusive strategies that support development of pattern perception in both the auditory and visuo-spatial domains and allow transfer of understanding across domains. This would allow greater opportunities for children to demonstrate their understanding of concepts in an inclusive manner and improve their performance in areas such as mathematics and music.

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AO, SG, and HT conceived the theoretical discussion and researched the literature. AO developed the theoretical framework and wrote the first draft of the manuscript. SM researched the literature, helped draft the manuscript and contributed to theoretical development. SK contributed to the theoretical discussion and helped shape the framework. MT supported the theoretical discussion. All authors reviewed and edited the manuscript and approved the final version of the manuscript.

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This research did not require ethics committee or IRB approval. This research did not involve the use of personal data, fieldwork, or experiments involving human or animal participants, or work with children, vulnerable individuals, or clinical populations.

Ethics

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Data Availability Statement

Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

Note

1. As we shall see, the concepts of *pattern* and *structure* are related but not identical. For the context of this paper, the authors define pattern as the manifestation of structure, in which the "where" and/or the "when" of something can be predicted from what has gone before, and (typically) the "what." In the visuo-spatial domain, for example, a line of equally spaced red snooker balls forms a pattern, since a further ball can be added that follows the "where" and the "what" of that which has been presented. In the auditory domain, a regular beat on a drum forms a pattern, since a further strike of the drum can be predicted from what has gone before. But imagine a mosaic, in which there are equal numbers of red, blue, yellow, purple, orange, and green tiles, arranged in random fashion. The distribution of tiles in relation to their color is structured, but a pattern is not formed, since it is not possible to predict what colour a given tile will be based on those around it. Similarly, "tonality" (which derives from the statistical distribution of pitches and intervals) is a form of musical structure but not pattern. It has to be acknowledged too that the term "pattern" is used in common parlance to mean any arrangement of things, whether they are orderly or not. Here we will use the term "pattern" with the specific meaning defined above.

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