Young children make their gestural communication systems more language-like: Segmentation and linearisation of semantic elements in motion events.

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Abstract

Research on Nicaraguan Sign Language, created by deaf children, has suggested that young children gesturally segment the semantic elements of events and linearise them in language-like ways. However, it is unclear whether this is due to children's learning processes or to a more general effect of iterative learning. Here, we investigated whether typically-developing children, without iterative learning, segment and linearise information. Gestures produced in absence of speech to express a motion event were examined in 4-year-olds, 12-year-olds and adults (all native English speakers). We compared the proportion of gestural expressions that segmented semantic elements into linear sequences versus those that encoded them simultaneously. Compared to adolescents and adults, children re-shaped the holistic stimuli by segmenting and re-combining its semantic features into linearised sequences. A control experiment ruled out that this was due to different event perception or memory. Young children spontaneously bring fundamental properties of language into their communication system.

Keywords: language acquisition, Nicaraguan Sign Language, iterative learning, pantomime

Introduction

All natural human languages share a number of universal organising properties, or 'design features' (Hockett, 1987), which are robust across cultures and conditions (Feldman, Goldin-Meadow & Gleitman, 1978). For instance, all languages break down holistically presented information into discrete segments and re-combine them into linear sequences. For example, a motion event that simultaneously represents both manner and path, such as rolling and descending, is linguistically expressed as a linear sequence of words expressing different aspects of the event (e.g., "ball rolling down the hill"). The present study investigated whether children show stronger tendencies to segment and linearise information in their communication systems compared to adolescents and adults. That is, it investigated whether children spontaneously bring in the design features of language into their communication system.

The critical role of children in language creation is particularly apparent in cases like deaf children raised in a hearing family without exposure to a sign language. These children have been shown to spontaneously invent their own gestural communication systems, known as 'home signs', (Fant, 1972; Feldman et al. 1978; Goldin-Meadow, 2003; Goldin-Meadow & Feldman, 1977). These home signs show core linguistic properties not observed in their parents' gesturing, including systematic ordering of semantic elements and syntactically conditioned omission of semantic elements that are inferable from the context (Goldin-Meadow, 2003). These structures in home signs have been shown to be common across deaf children (Goldin-Meadow & Mylander, 1983) and even across cultures

(USA and Taiwan) (Goldin-Meadow & Mylander, 1998, Goldin-Meadow, Özyürek, Sancar & Mylander, 2009).

By definition, a home sign system is used only by a deaf child, and the system does not develop into a full-blown language. In contrast, when a group of deaf children form a community and the communication system is passed onto younger generations of deaf children, the system becomes a full-blown language relatively quickly. Nicaraguan Sign Language (NSL) is such a case (e.g., Kegl, Senghas, & Coppola, 1999; Senghas & Coppola, 2001; Senghas, Kita, & Özyürek, 2004), as well as a similar case of a new sign language, ABSL, reported by Sandler, Meir, Padden & Aronoff, 2005 (see also Senghas, 2005). Until the first special education school in Nicaragua was established in 1977, deaf Nicaraguan children were largely isolated from each other. The language of instruction at their special education school was Spanish, and teachers did not use any sign language. However, when the school created an opportunity for deaf children to communicate with each other gesturally, their gestural communication system soon developed into a full-blown language. Every year, a new cohort of children joined the school and they learned this language from the older children in the school. Rather than just learning the sign language, the children also changed the language in a profound way.

In its initial 10-15 years, NSL developed an increasingly strong tendency to segment complex information into elements and expressed them in a linear fashion (Senghas et al., 2004). Senghas et al. (2004) investigated how a complex motion event, containing simultaneous manner and path, was expressed by signs produced by successive cohorts of NSL signers, who entered the special education school as young children (six or younger) at different periods in the history of NSL, as compared to the speech-accompanying gestures

produced by native Spanish speaking adults. The first cohort signers, who entered the school before 1983, were the first to develop the home-signs into a language-like system. The second (1984 - 1993) and third cohorts (after 1994) subsequently joined the community. The first cohort signers, like adult Spanish-speakers, frequently expressed both manner and path in a single sign (gesture); in contrast, the second and third cohort signers showed stronger tendencies to segment manner and path in two separate signs and linearly ordered the two elements.

It can be argued, for two reasons, that pre-adolescent children were driving the NSL's transition into a more segmented and linear system. First, the signing by the first cohort was similar to the hearing speakers' gestural model. The first cohort signers, who reached adolescence by mid 1980s, did not pick up the second cohorts' innovations. Second, another grammatical innovation in NSL by the second cohort signers was driven by pre-adolescent children. Many sign languages use locations in signing space to keep track of referents, and hand movements for verbs are inflected towards locations with relevant referents to indicate who/what the subject and the object are (e.g. Klima & Bellugi, 1979). The frequency of such inflection of verbs increased significantly in the second cohort signers, as compared to the first cohort signers; however, this effect occurred among second cohort signers who entered the school at 10 years old or younger but not among those who entered older than 10 years old (Senghas & Coppola, 2001). Together, these findings indicate that pre-adolescent children were the primary driving force of structural change in NSL.

While Senghas et al.'s (2004) result may be explained by children's natural tendency to segment and linearise communicative information, a study on the cumulative cultural

evolution of language has since provided an alternative. That is, the process of transmission of language from one learner to the next can also shape language into more segmented and linear forms (Kirby, Cornish & Smith, 2008). In this study, adult participants learned an artificial language that provided labels for motion stimuli that had three simultaneous aspects: object shape, object color, and movement trajectory. In the seed language, given to the first participant in the transmission chain, the labels were arbitrary and holistic, in the sense that the labels could not be broken down into parts that separately encoded the three aspects of the stimuli. The artificial language was transmitted from one language learner to another; in other words, the output from one learner was used as the input for the next learner. When participants were prevented from simplifying the language by not distinguishing certain aspects, the language became more segmented and linear through transmission: e.g., the initial, middle and the final part of the label encoded color, shape and trajectory, respectively. Computational and mathematical models have similarly indicated that the iterative learning processes themselves can explain various aspects of the structure of language (e.g. Brighton, 2002; Christiansen & Chater, 2008; Kirby, Dowman & Griffiths, 2007; Kirby, Smith & Brighton, 2004; Scott-Phillips & Kirby, 2010; Smith, Brighton & Kirby, 2003).

Given these insights from iterative learning studies, it is therefore possible that the shift of NSL into more segmented and linear organisation (Senghas, et al., 2004) may simply exemplify a general effect of transmitting a language across cohorts. Thus, the results in Senghas et al. (2004) may not reflect clear evidence that young children have age-specific biases to shape their communication system into more segmented and linear organisation. Therefore, the present study examined whether typically developing English-

speaking children showed a stronger tendency to segment and linearise information than adolescents and adults in a communication task that did not involve iterative learning. We presented video stimuli of motion events with manner and path and asked the participants to depict the scene with pantomimes, that is, gestures without speaking.

Hearing adults, without knowledge of sign language, introduced language-like structure in some situations, but not in others. The adults consistently ordered semantic elements when pantomiming an event with multiple components (Gershkoff-Stowe & Goldin-Meadow, 2002; Goldin-Meadow, McNeill, & Singleton 1996). Furthermore, their pantomime order remained the same, irrespective of the canonical word order in the participants' native languages (Goldin-Meadow, So, Özyürek, & Mylander, 2008), indicating that adults can introduce language-like structure in pantomime communication. Hearing adults, however, did not segment and linearise information when pantomiming motion events containing manner and path, unlike deaf children using home signs (Özyürek, Furman, & Goldin-Meadow, in press; Goldin-Meadow, Namboudiripad, Mylander, & Özyürek, in press). No previous studies have directly compared pantomime representations between hearing children and hearing adults; thus, it is not yet known whether hearing children are more likely to introduce language-like structure, in particular, segmented and linear organisation, in pantomiming than hearing adults.

In the present study, we compared three age groups of hearing participants: four-year-olds, 12-year-olds and adults. Four-year-olds were selected for three reasons. First, children at this age are still thought to be within the sensitive period for language acquisition (Lenneberg, 1967; Newport, 1988). Second, deaf children who were first exposed to NSL below six years showed the strongest tendencies for grammatical

innovation (Senghas & Coppola, 2001). Third, the mean age for the first exposure to NSL in Senghas et al. (2004) was four years old. We chose 12-year-olds as the Adolescence Group as, firstly, studies have highlighted a decline in children's sensitivity to the structural patterns of language from around age 12 (e.g. Johnson & Newport, 1989; Newport, 1988) and secondly, the NSL signers whose first exposure to NSL occurred at ten years or older did not show grammatical innovation (Senghas & Coppola, 2001).

Based on the NSL results (Senghas, et al., 2004; Senghas & Coppola, 2001) and the home sign results (Özyürek et al., 2007), we predicted that four-year-olds should show stronger tendencies to re-organise holistically presented stimulus events into segmented and linear encoding in pantomime, as compared to adolescents or adults. We ran a control experiment on recognition memory for events to rule out the possibility any difference in pantomimes could be attributed to limited event perception and memory.

Methods

Participants

Native English speakers in the UK participated (the mean ages in brackets): 37 four-year-olds (4.5 years), 28 adolescents (12.4 years) and 35 adults (21.5 years). See Supplementary Material for more details.

Materials

Pantomime task

The stimuli were eight animation clips of a motion event (see Supplementary Material), depicting either a smiling square or circle on a green 'hill' slope against a blue 'sky' background (Figure 1). Manner and path of the motion event were presented simultaneously, with the shape either ascending or descending the slope, while performing either eleven bounces or rotations. The eight different clips represented all combinations of the following features: the square or circle shape, rolling or bouncing (motion), up or down the slope (path).

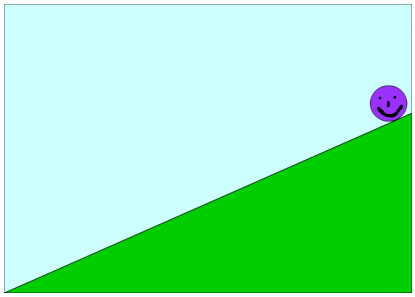


Figure 1. Depiction of the animation stimuli used in the Pantomime task. The circle (or square) either bounced or rolled up or down the slope.

Recognition task

Each of the eight 'simultaneous' animation clips used in the Pantomime task were coupled with an additional clip in which everything remained identical except that manner and path were presented sequentially. For example, the square bounced at the bottom *and then* slid up the hill in a constant position (manner-then-path). For each manner presentation, the shape bounced or rotated eleven times. Clip duration matched that of the 'simultaneous' clips.

Procedure

All participants were tested individually. Each participant was seated at a table, facing the laptop computer, next to an experimenter. Another experimenter sat opposite, approximately 1.5 meters away, to film the session. All participants did the Pantomime task before the Recognition task.

Pantomime task

Children performed two warm-up trials (see Supplementary Material for details). In the experimental trials, the participant watched each animation clip and then was asked to use either hand to show the experimenter what the shape (an animated circle or a triangle) had done, without speaking or making sounds. This was repeated for eight animation clips. The clips were ordered in such a way that same type of manner or path was repeated at most twice and there were at least two intervening items between repetitions of the same manner or the same path. Participants were encouraged to communicate with the experimenter rather than to the camera. If the participant requested to see a clip again, or if there were surrounding distractions, a given stimulus was shown up to three times.

Recognition task

The participant was told that they would be watching pairs of clips and that they would need to state whether the clips were either the same or different, in terms of the way that the shape moved. The first clip always showed manner and path simultaneously and the second clip was the same as of the first clip half of the time, and it showed manner and path sequentially the other half of the time. The participant watched a total of eight clip pairs

and were asked to explain what differed if they said the second clip differed from the first one. Correct identification of differing clips was indicated by verbal/gestural explanation of the presence of two phases, either temporal segmentation, or separation of manner and path (e.g. expressions 'and then' or 'at the end'). Incorrect identification of differing clips (i.e. misidentification or detecting irrelevant differences) or inconclusive explanations (not clearly indicating an understanding of the presence of two phases in the sequential stimulus) were recorded.

Variables

See Supplementary Material for more information on dependent and independent variables.

Coding

Gestures were segmented into movement phases following the procedure in Kita, van Gijn, and van der Hulst (1998). The 'stroke phase', the meaning carrying movement phase (Kita, van Gijn, & van der Hulst, 1998), was coded into four categories: (1) *Manner-segmentation,* a gesture expressed at least one complete cycle of either a rotation (roll) or an upward or downward sweep (bounce), (2) *Path-segmentation*, a gesture expressed a straight trajectory, (3) *Simultaneous manner-and-path*, A gesture simultaneously expressed manner and path, (4) *unclear.* See the Supplementary Materials for more details.

Based on the gestures coded for each trial, trials were classified into the following four mutually-exclusive types: (1) 'simultaneous manner-and-path', responses including only gestures that expressed manner and path simultaneously within a single movement, (2) 'both manner-and-path-segmentation', responses including gestures expressing both manner and path as separate elements, (3) 'manner-segmentation only', responses

including a segmented manner but not path, (4) 'path-segmentation only', responses including segmented path but not manner. The responses of 'manner-segmentation only', 'path-segmentation only' or 'both manner and path segmentation' could also include additional 'simultaneous manner-and-path' gestures. Unclear gestural responses were excluded from analyses.

Inter-Observer Reliability

A second coder independently coded 82% of the trials. There was 92.3% agreement for the presence of Manner gestures in a given trial (Cohen's *kappa* = .748, $p < .001$), 96.3% agreement for the presence of Path gestures (Cohen's *kappa* = .683, $p < .001$), and 96.8% agreement for the presence of Manner-Path Simultaneous gestures (Cohen's *kappa* = .815, $p < .001$).

Results

Pantomime task

We compared the proportion of gesture response types across age groups. There was a significant effect of age on the proportion of all four gesture response types (Figure 2): those with both manner-and-path-segmentation *(*Kruskal-Wallis, $\chi^2 = 24.32$, $df = 2$, $p < .001$, two-tailed, as are all subsequent analyses), those with manner-segmentation only ($\chi^2 = 44.22$, $df =$, $p < .001$), those with path-segmentation only ($\chi^2 = 13.08$, $df = 2$, $p < .001$) and those with only simultaneous manner-and-path *(*$\chi^2 = 66.96$, $df = 2$, $p < .001$). Only children produced responses in which gestures sequentially expressing manner-and-path-

segmentation. Post-hoc analyses (Mann-Whitney with Bonferroni correction) revealed that children produced significantly more manner-segmentation only responses and more path-segmentation-only responses than adolescents (manner-segmentation only, $p < .001$, path segmentation only, $p = .015$) or adults *(*manner-segmentation only, $p < .001$; path-segmentation only, $p = .012$). Children produced significantly fewer gestures containing only simultaneous manner-and-path, compared to adolescents ($p < .001$) or adults *(*$p < .001$). There were no significant differences at all between adolescents and adults..

Next, we compared the proportions of the four response types within each age group to see which was most dominant. There were significant differences in the proportion of each response type produced by children (Friedman, $\chi^2 = 35.90$, $df = 3$, $p < .001$), adolescents ($\chi^2 = 71.36$, $df = 3$, $p < .001$) and adults ($\chi^2 = 87.81$, $df = 3$, $p < .001$). Post-hoc analysis (Mann-Whitney with Bonferroni correction) revealed that responses with manner-segmentation only and only simultaneous manner-and-path significantly dominated children's responses as compared to responses containing both manner-and-path-segmentation or those with path-segmentation only (All comparisons, $p < .001$). Whilst adolescents produced more manner-segmentation only responses than responses with both manner-and-path-segmentation ($p < .001$), responses expressing only simultaneous manner-and-path dominated over all other responses (All comparisons, $p < .001$). In adults, gestures expressing only simultaneous manner-and-path completely dominated over all other responses (all comparisons, $p < .001$).

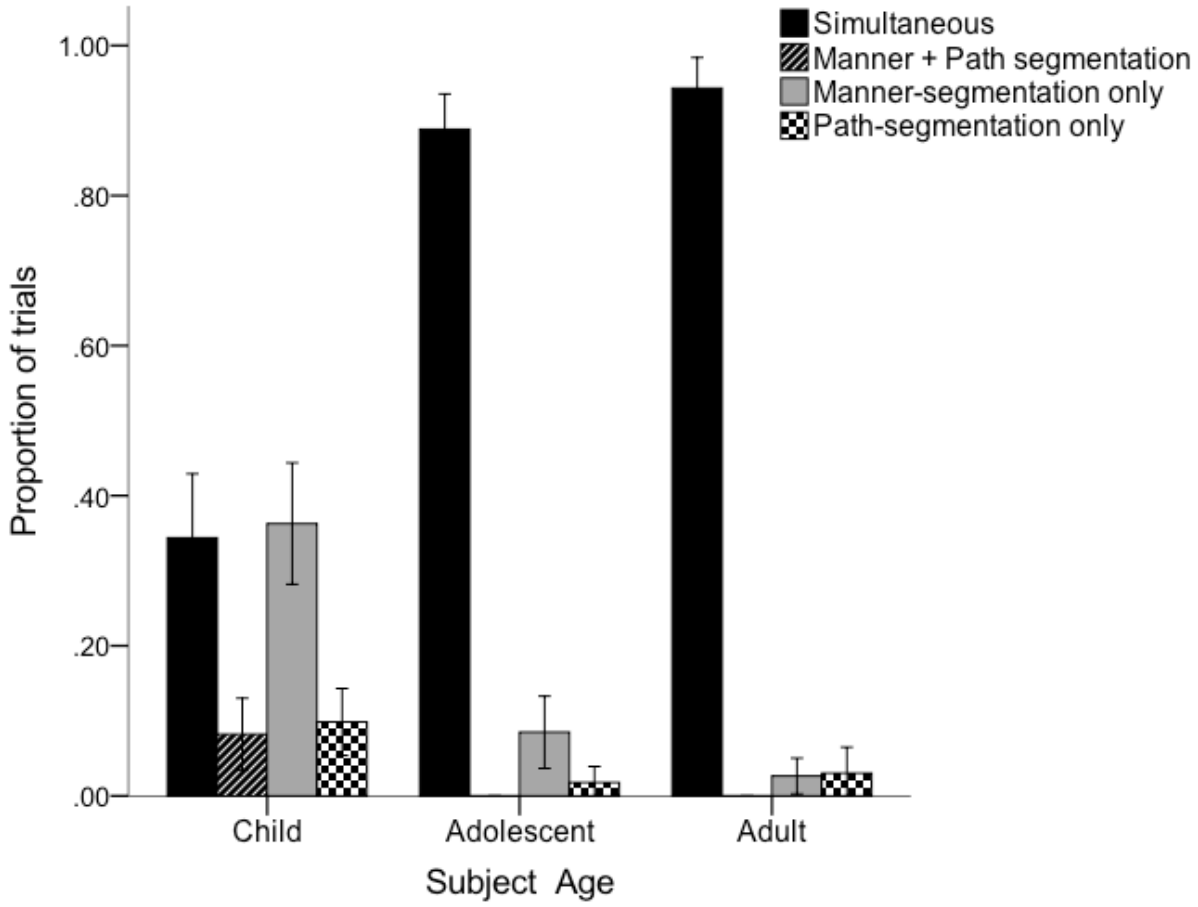


Figure 2. Mean (+ /- SE) proportion of trials containing four types of gesture responses, produced by children, adolescents and adults in the Pantomime task.

Finally, following the analysis in Özyürek, Furman and Goldin-Meadow (in press), we compared the age groups, regarding the proportions of trials with "mixed" gestural responses (manner gestures and/or path gestures, combined with simultaneous gestures). The age groups significantly differed from each other: Child, M = .40, SE = .040; Adolescent, M = .098, SE = .023; Adult, M = .043, SE = .018; Kruskal-Wallis, χ^2= 47.37, df = 2, p< .001;

significant post-hoc tests, using Mann-Whitney with Bonferroni correction, Child > Adolescent, Adults.

Recognition task

All three age groups showed a high degree of competence in the recognition task. The proportions of correct responses, *M* (*SD*), were as follows: children 95 (.11), adolescents 1.00 (.004) and adults 0.99 (.005). While there was a significant effect of age on the proportion of correct response (Kruskal-Wallis, $\chi^2 = 8.838$, $df = 2$, $p = .012$), post-hoc analysis failed to determine the locus of the effect.

Descriptive analysis of children's verbal explanations for differences they observed provided further support that event perception and event memory do not underlie their segmented and linearised gestures in the Pantomime task. When children correctly responded 'different', they provided accompanying explanations that correctly expressed their understanding of the difference between simultaneous and sequential motion events. In the few cases where children incorrectly responded 'different', their subsequent explanations were inconclusive, in the sense that explanations that did not refer to the simultaneity or sequentiality of manner and path. This suggests that the few incorrect responses did not reflect an inability to distinguish between simultaneous and sequential events.

To further verify that children's performance on the Recognition task could not explain patterns of gesture responses in the Pantomime task, we correlated the proportions of the gesture types produced in the Pantomime task (reported in Figure 2) with the proportion of correct responses in the Recognition task. No significant

correlations (Spearman correlation) were found: both manner-and-path-segmentation: r_s = - .031; manner-segmentation only*:* r_s = .111, path-segmentation only r_s = -.113; or only simultaneous manner-and-path: r_s= .077.

Discussion

We compared how young children (four-year-olds), adolescents (12-year-olds) and adults depicted the manner and path of a motion event using pantomimes (gestures without speaking). Compared to adolescents and adults, children showed the strongest tendencies to segment and linearise manner and path of a motion event that had been represented to them simultaneously in the stimulus events. Moreover, the difference in the pantomime performance between the three age groups *cannot* be attributed to young children's poor event perception or memory because the children performed very well in the event recognition task and because the children's performances in the pantomime task and the recognition task did not correlate. The results indicate that young children, but not adolescents and adults, have a bias to segment and linearise information in communication.

The children often combined segmented expressions with simultaneous expressions within a single response. They produced such "mixed" responses (manner and/or path gestures, combined with simultaneous gestures) more often than adolescents and adults. Mixed expressions were common in home signs (Özyürek, Furman & Goldin-Meadow, in press) and the first cohort signing in Nicaraguan Sign Language (Senghas, Özyürek, & Goldin-Meadow, 2010). Such expressions may be important steppingstones towards more

fully segmented and linear forms of communication (Özyürek, et al. in press; Senghas et al. 2010).

Young children were more likely to segment manner than path. This may be because the children found manners to be more noteworthy, similarly to the suggestion that co-speech gestures are more likely to be produced when communicating noteworthy information (McNeill, 1992). Speech-accompanying gestures encoded path more often when the change of location was a prerequisite for the next event in the story, making path more noteworthy (Kita & Özyürek, 2003).

The children's bias towards segmented and linear organisation of communication dovetails with the finding that iterative learning gradually makes language more segmented and linear (Kirby et al., 2008). As all languages are learned by children and transmitted iteratively from generation to generation, these two biases may explain why human language universally has segmented and linear organisation, in general.

Languages are, of course, not completely segmented and linear, and have synthetic expressions, in which a single linguistic form simultaneously encodes multiple semantic elements. Segmented forms may be more common in labels for events than objects because event representation may include more semantic elements. Synthetic expressions may also arise due to demands on efficiency in encoding, The current status of languages may reflect equilibrium points for various forces that shape language.

The notion that properties of language might be a product of children's natural tendencies to shape their communication system is also compatible with findings from children's home signs. Despite lack of access to conventional language input, deaf children spontaneously create home signs that exhibit various features of language (Feldman,

Goldin-Meadow, & Gleitman, 1978; Goldin-Meadow, 2003; Goldin-Meadow & Mylander, 1983, 1998; Özyürek, et al., in press).

The tendency for segmented and linear organisation in pantomime gestures was observed only in young children. This is compatible with the finding that pre-adolescence children were the driving force behind grammatical innovation in NSL (Senghas & Copolla, 2001; Senghas, Kita & Özyürek, 2004) and that pre-adolescence exposure to second language is important for acquisition of morphosyntax (Johnson & Newport, 1989).

Why do young children have a bias to segment and linearise information in communication? One possibility is that this tendency may be due to young children's limited processing capacity. Compared to adults, children may not be able to process two semantic elements within a conceptual planning unit for communication. They may need to conceptually plan one semantic element at a time. There is some evidence that young children have a smaller capacity for speech production than adults. For example, English-speaking children often omit the subject noun phrase, even when it is not grammatically permitted to do so. Children are more likely to do so when the sentence is more complex (e.g., a sentence with negation, L. Bloom, 1970; the sentence contains more morphemes, P. Bloom, 1990; Freudenthal, Pine & Gobet, 2007). Similar capacity limitation for conceptual planning for communication may have caused children to express one semantic element at a time.

The participants in the current study spoke English and the segmentation and linearization tendency observed may be a consequence of learning this particular language or any language. This explanation, however, is not very plausible because adults who had the most experience in using the English language showed very little tendency for

segmentation and linearisation. In addition, cross-linguistic comparison of children's pantomime is an important future topic.

One limitation of the current study is that pantomimes were not compared with speech-accompanying gestures. A previous study on speech-accompanying gesture (Özyürek, et al. 2008) showed that young children segmented manner and path information more often than adults for English speakers (but not for Turkish speakers). It is unlikely, however, that the English-speaking children in the current study simply transferred their representations in speech-accompanying gestures into pantomimes for two reasons. First, the age difference was far more dramatic in the current study than in the study on speech-accompanying gestures (Özyürek et al., 2008)[1]. Second, at least for adults, the nature of representation in pantomimes qualitatively differs between that in speech-accompanying gestures (Goldin-Meadow et al., 1996; Özyürek, et al. in press). An important future research topic is to compare representations in children's pantomimes and speech-accompanying gestures.

To summarise, the present study has provided evidence that typically-developing young children spontaneously shape their gestural communication systems into more segmented and linear organisation. All human languages may segment complex information and linearly express semantic elements because all languages are learned, and therefore, shaped by young children.

Author contributions

SK and BH developed the study concept. SK, ZK, and SP developed the design. ZK and SP collected and coded the recordings, under SK's supervision. ZK, SP and SK analysed and

interpreted the data. ZK and SK drafted the manuscript, with BH providing critical revisions. All authors approved the submitted version of the manuscript.

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Note

1. The absolute levels of segmentation cannot be compared between the two studies because the stimuli events (see Kita et al., 2007 for the stimulus type effect) and the dependent variables differed.

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