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Perceptual and positional saliencies influence children's sequence learning differently with age and instructions at test

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ABSTRACT
There is growing evidence that, faced with a complex environment, participants subdivide the incoming information into small perceptual units, called chunks. Although statistical properties have been identified as playing a key role in chunking, we wanted to determine whether perceptual (repetitions) and positional (initial units) features might provide immediate guidance for the parsing of information into chunks. Children aged 5 and 8 years were exposed to sequences of 3, 4, or 5 colours. Sequence learning was assessed either through an explicit generation test (Experiment 1) or through a recognition test (Experiment 2). Experiment 1 showed that perceptual and positional saliencies benefited learning and that sensitivity to repetitions was age dependent and permitted the formation of longer chunks (trigrams) in the oldest children. Experiment 2 suggested that children became sensitive to perceptual and positional saliencies regardless of age and that the both types of saliencies supported the formation of longer chunks in the oldest children. The discussion focuses on the multiple factors intervening in sequence learning and their differential effects as a function of the instructions used at test to assess sequence learning.

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The environment around us is made up of information that is usually arranged in continuous form, such as objects in visual scenes or words in a speech stream. A quick check of one's own behaviour makes it clear that we do not directly access all the available information. Instead of this, we successively allocate our attention to certain elements. This inherent phenomenon is due to the limited capacities of our cognitive system (Cowan, 2000), with the result that parsing the world into chunks appears to be a mandatory process (Servan-Schreiber & Anderson, 1990). The literature on implicit learning has indeed repeatedly shown that information is naturally parsed into segments or chunks. For instance, in the context of the implicit learning of sequences of visual symbols or tones, Perruchet and Gallego (1997) claimed that their participants encoded the material as a succession of disconnected small units (see also Dienes, Broadbent, & Berry, 1991; Perruchet & Pacteau, 1990). Similarly, participants who were asked to write down the sequences of letters they were presented with during an incidental exposure phase frequently reproduced them as distinct chunks made up of groups of letters (Servan-Schreiber & Anderson, 1990).

We may wonder what the main factors that provide guidance for parsing complex material into chunks actually are. It is generally accepted that fragment-based learning results from the concatenation of frequent co-occurring elements (e.g., Dulany, Carlston, & Dewey, 1984; Servan-Schreiber & Anderson, 1990). Indeed, sensitivity to statistical features plays a key role in the formation of chunks due to the effects of frequency (Perruchet & Pacteau, 1990; Stadler, 1992), transitional probability (Fiser & Aslin, 2001; Poletiek & Wolters, 2009), and contingency (Perruchet & Peereman, 2004). However, several learning studies have reported adaptation to structured material following only brief exposure (Meulemans, Van der Linden, & Perruchet, 1998), while statistical features necessarily require a minimum amount of exposure to the

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material before they can influence learning. Other sources of information may thus play a more immediate role in the formation of chunks.

The immediate spatial (or temporal) repetition of one and the same element appears to be a serious candidate. According to Gestalt theory (Attneave, 1954), the principles of similarity and continuity make the spatial repetitions of elements salient—that is, likely to capture attention (Kruschke, 2010). Several studies have reported that knowledge acquired during an incidental learning episode embeds information about repeated elements (Reber & Allen, 1978; Tunney, 2005, 2010). For instance, sequences of tones containing repeated adjacent or non-adjacent elements (ABB or ABA) have been found to be learned more efficiently than ordered sequences of tones (low–high–medium or medium–high–low; Endress, Dehaene-Lambertz, & Mehler, 2007) or than sequences with no repeated tones (Monaghan & Rowson, 2008).

An additional source of information during sequence learning takes the form of positional cues. Participants develop a particular sensitivity to the fragments in the first and last positions within sequences (Mathews et al., 1989; Redington & Chater, 1996). For instance, Conway and Christiansen (2005, 2006, 2009) observed that the initial and final fragments contributed greatly to their participants' performance in a grammaticality judgement task, and that this phenomenon was particularly accentuated for the initial elements of visually displayed sequences, as had already been observed by Beaman (2002).

In light of the fact that perceptual and positional saliencies are very likely to capture attention and provide early guidance during the parsing process, the present study deals with the question of the early formation of chunks and their consolidation through associative learning (e.g., Mackintosh, 1975). Jones (2012) pointed out that reference to the chunking process is relatively absent from the developmental literature whereas it may account for many aged-related changes in task performance. Indeed, chunking[1] permits one to increase the amount of information that one can process simultaneously despite limitations in attentional and short-time memory capacities (e.g., Cowan, 2001, 2000; Gobet & Clarkson, 2004) or of processing speed (Kail, 1988, 1991), these functions improving notably during childhood and particularly between 5 and 8 years of age (Gathercole, 1998). Because segmentation of the material is thought to depend on the effects of interactions between the type of material used in the learning situation and the constraints of the human attentional and memory systems (Perruchet & Vinter, 1998), we aimed at studying the respective contributions of perceptual and positional saliencies during the incidental learning of coloured sequences in 5- and 8-year-old children. In the present experiment, all sequences contained frequent first and second bigrams, as compared to the successive bigrams. The first bigrams benefited, in addition, from positional salience. Concerning the second bigrams, only half of them benefited, in addition, from perceptual salience through the systematic introduction of an adjacent repetition of colours (blue–yellow–yellow for instance). For sake of simplification, we labelled this last type of sequence "REP sequences" (blue–yellow–yellow) and the others "non-REP sequences" (e.g., blue–yellow–green). The participants were randomly assigned to one of these sequences (REP group or non-REP group). Importantly, the first and second bigrams of the sequences were equally frequent whatever the type of sequence, and repetitions did not appear at locations other than the second bigrams of the REP sequences. After an incidental training phase, learning was assessed by means of an explicit task, asking children to generate coloured sequences that they were fully certain to have seen during the training phase.

We hypothesized that the REP group should generate more frequent bigrams (those present in the first and second positions within the training sequences) than the non-REP group. Although frequency was constant across all sequences, frequent bigrams in the REP sequences were reinforced by two types of saliencies: positional (first bigram), like the non-REP sequences, and perceptual (repetition at the second bigram). The REP group should produce more correct (i.e., seen during training) second bigrams than the non-REP, and children should become more sensitive to first bigrams than to second bigrams when the latter were not perceptually salient—that is, in the non-REP group. Sensitivity to repetition information should not be age dependent because the developmental literature contains numerous reports of children's very early sensitivity to repetition effects (Johnson et al., 2009; Gomez & Gerken, 1999; Marcus, Vijayan, Rao, & Vishton, 1999; Witt & Vinter, 2012). By contrast, we expected the 5- and 8-year-old children to learn chunks of different lengths since the larger attentional capacity of older children should allow them to form larger chunks (Cowan, 2000; Oberauer, 2002; Witt, Puspitawati, & Vinter, 2013).

Table 1. Characteristics of the groups enrolled in Experiment 1.

Age (years)	Mean age (years, months)	Sex	Group	*N*	Mean age (years, months)	Sex
5	5,4 (span: 4,11–5,6)	14F, 14M	REP	14	5,6	7F, 7M
			non-REP	14	5,2	7F, 7M
8	8,3 (span: 7,9–8,5)	14F, 14M	REP	14	8,4	7F, 7M
			non-REP	14	8,2	7F, 7M

Note: REP = repetitions; non-REP = no repetition; F = female; M = male.

Experiment 1

Method

Participants

Fifty-six kindergarten and second graders (28 female and 28 male), aged 5 (*N* = 28) or 8 years (*N* = 28), participated in the experiment. Within each age group, the children were randomly divided into two groups: the REP group (*N* = 14) and the non-REP group (*N* = 14). Their vision was normal or corrected, and they were able to name the five colours[2] used in this study. None of these children presented any developmental or attentional deficits. Written parental consent was obtained for each children, and the study was approved by an institutional review board. Table 1 presents the characteristics of the participants.

Materials

We employed a computer game involving the presence of 3-, 4-, and 5-colour flags during a "tug-of-war" tournament organized by pandas (Figure 1A). All instructions were delivered by a pre-recorded voice along the task. The flags presented during the training phase corresponded to sequences of colours that we wished to confront the participants with (5 colours in total). For the needs of our experiment, two types of sequences were built. All the series were composed of eight sequences: 2 three-colour sequences, 3 four-colour sequences, and 3 five-colour sequences.[3] At test, 25 coloured squares (5 blue, B; 5 green, G; 5 red, R; 5 yellow, Y; and 5 turquoise, T) were used by children to build a flag (Figure 1B), in order to not limit the participants in their production.[4]

Constitution of the REP and non-REP sequences. The REP and non-REP sequences consisted of 10 or 12 distinct bigrams, which differed in their frequency of occurrence. Both the REP and non-REP sequences had only two legal bigrams in first position (respectively, BY and RG or BY and RB), each of which occurred with identical frequency. They differed in that the two legal bigrams in second position contained adjacent repetitions in the REP sequences (YY and GG) but not in the non-REP sequences (YG and BT). These occurred with almost identical frequency, with a slight advantage for the non-REP sequences. As a consequence, the two legal first trigrams included a repetition in the REP sequences (BYY and RGG), but not in the non-REP sequences (BYG and RBT).

The colours were assigned by chance to the various positions within the flags so that 14 specimens were constructed for each type of sequence (per age group). By way of illustration, the items in the REP sequences could be: BYY–RGG–BYYV–BYYR–RGGY–BYYTG–RGGYB–RGGBT; and in the non-REP sequences: BYG–RBT–BYGT–BYGR–RBTG–BYGTR–RBTYG–RBTGY. All the sequences consisted of eight

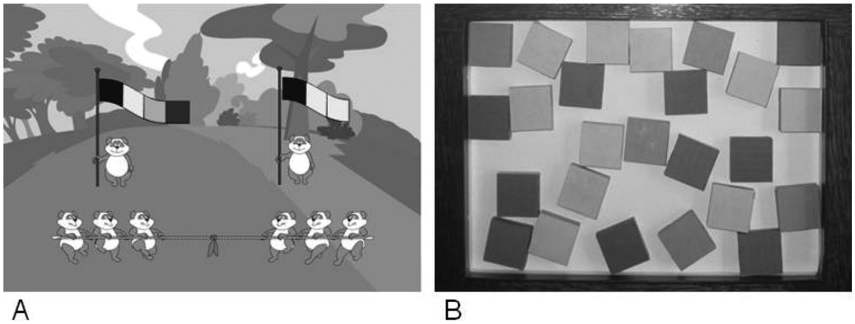

Figure 1. Illustrations of the video game (A. Tug of war tournament; B. Coloured squares).

Table 2. Statistical distribution of the bigrams in the REP and non-REP sequences.

Sequences	Units	Occurrences (xy)	x	TP (xy/x)	Chunk strength[a]
REP sequences					
First bigrams	RG	4	5	.80	3.5
	BY	4	6	.667	3
Repetitions	YY	4	10	.40	1
	GG	4	10	.40	1
Other bigrams	BT	1	6	.167	−1.5
	GY	2	10	.20	−1.5
	GB	1	10	.10	−3.5
	YG	1	10	.10	−3.5
	YB	1	10	.10	−3.5
	YT	1	10	.10	−3.5
	YR	1	10	.10	−3.5
	TG	1	2	.50	0.5
Non-REP sequences					
First bigrams	BY	4	8	.50	2
	RB	4	6	.6667	3
Second bigrams	YG	5	6	.8333	4.5
	BT	4	8	.50	2
Other bigrams	GR	1	7	.1429	−2
	GT	2	7	.2857	−0.5
	GY	1	7	.1429	−2
	TG	2	6	.3333	0
	TR	1	6	.1667	−1.5
	TY	1	6	.1667	−1.5

Note: REP = repetitions, non-REP = no repetition; TP = transitional probability; B = blue; G = green; R = red; Y = yellow; T = turquoise.

[a] Chunk strength: $xy - [(x - xy) \times 0.5]$. We used the calculation method proposed by Perruchet and Pacton (2006), while taking account of the fact that the memorization of chunks (i.e., consolidation and forgetting) depends on interference. Each occurrence of xy strengthens it by 1 unit, and each occurrence of another letter pair beginning with x decreases the strength of xy, as in the PARSER model (Perruchet & Vinter, 1998). Student's t tests showed that bigrams' frequency, transitional probabilities, and chunk strength did not differ between the REP and the non-REP sequences (respectively, $p = .53$, $p = .51$, $p = .19$).

items: 2 three-colour sequences, and 3 four- and five-colour sequences. The REP and non-REP sequences were built in order to make the statistical distribution of their respective bigrams equivalent, especially those in first and second positions within the sequences, thus enabling us to question the role played by perceptual or positional saliencies in learning, beyond the contribution of statistical information. Table 2 presents the statistical distribution (frequency, transitional probabilities, and chunk strength) of the bigrams composing the REP and non-REP sequences.

Procedure

Presentation and training. The experimental session started with a 20-min exposure phase during which the child was installed in front of a computer and shown a video-game. A pre-recorded voice displayed the following instructions to the participant: "*Hello, today the pandas have organized a 'tug-of-war' tournament. Each team of pandas will show you its pretty flag.*[5] *Press 'start' to see the first team's flag*". At this stage, the child shown the colours of the flag appearing sequentially from left to right, one at a time every 500 ms, until the flag was complete, then the child heard the instruction: "*Now, press 'start' to see another team's flag*". The eight flags (or sequences) were successively presented in a random order. The instructions then continued: "*Now, the tournament is going to start. Press 'start' to see the first team's flag*" (the first flag was displayed one colour at a time until it was complete). "*Press 'start' to see the second team's flag*" (the second flag was displayed). "*Now, press 'start' to start the match*". The two teams of pandas came face to face until one of the teams won (see Figure 1A). The two flags remained visible during the match, which was concluded with a brief animation. This procedure was repeated for 16 matches. The children thus saw the eight flags five times each, one time each during the presentation phase and four times each during the tug-of-war tournament. In order to prevent potential emotional effects on incidental learning performance due to the winning/losing status of the teams, all the teams (flags) won and lost twice, and the position (left or right) of the winning team was random.

Test. The training phase was followed by a 5-min test phase, which consisted of an explicit generation task in which each child was asked to produce a flag that he or she was completely confident of having seen during the training phase. After receiving a box containing 25 coloured squares (5 blue, 5 green, 5 red, 5 yellow, and 5 turquoise; Figure 1B), the child heard the following instructions:

> A short while ago, you saw the pandas taking part in the tug of war tournament with their flags. I'm going to ask you a question about the pandas' flags, the flags you have seen. Look at this box, it contains the colours used by the pandas. Can you make a whole flag that belonged to the pandas and that you are absolutely sure you saw during the game? Try to remember the pandas' flags, and make a flag when you are absolutely sure you remember a flag you saw during the game.

No information related to the length of the flag to produce was indicated to the child in order to not limit the child during his or her generation. Children had to produce only one flag because preliminary investigations revealed that many children refused to produce more than one flag, probably because the instructions strongly emphasized the need of accuracy in their production. In addition, we choose to use an explicit task in order to restrict contamination of their production by spontaneous generation biases, especially in young children, like repetition avoidance, or random or counterbalanced generation strategies (Witt & Vinter, 2011).

Coding of the data. We coded the presence of correct frequent bigrams (those present at first and second positions in the training sequences) in the flags produced at test. This coding was performed regardless of the position at which these units appeared within the flags built by the participants. We were indeed interested to test whether incidental learning of a unit was facilitated by its perceptual or positional salience, and not whether its specific location in a sequence could also be learned.[6] In addition, we coded the presence of correct first trigrams in the children's response at test. We focused our analyses on the initial part of the training sequences, conforming to previous findings reporting that participants became preferentially sensitive to the beginning of sequences, when displayed visually (Beaman, 2002; Conway & Christiansen, 2005, 2006, 2009). The frequencies of correct units were calculated as a function of the flag's length within which these units were generated. For example, a correct bigram scored .50 in a three-colour flag (1 occurrence out of 2 possible bigrams), .33 in a four-colour flag (1 out of 3), and so on.

A 2 (group: REP or non-REP) × 2 (age: 5 years or 8 years) between-groups analysis of variance (ANOVA) was carried out on the frequencies of production at test of the frequent first bigrams and second bigrams of the training sequences (grouped together or not) and of the first correct trigrams.

Results

Sensitivity to correct frequent bigrams: An advantage for the REP group?

A 2 (group: REP or non-REP) × 2 (age: 5 years or 8 years) ANOVA on the frequencies of correct frequent bigrams revealed that the REP group performed better (23.7%) than the non-REP group (14.3%), $F(1, 52) = 8.45$, $p < .01$, $\eta_p^2 = .14$, and that the 8-year-olds (25.4%) outperformed the 5-year-olds (12.5%), $F(1, 52) = 16.11$, $p < .001$, $\eta_p^2 = .24$. In addition, the Group × Age interaction effect was significant, $F(1, 52) = 4.7$, $p < .05$, $\eta_p^2 = .08$, revealing that the performance did not differ with age in the non-REP group, $t(26) = 1.5$, $p = .15$, while the 8-year-olds outperformed the 5-year-olds in the REP-group, $t(26) = 3.92$, $p < .001$, $d = 0.33$. Thus, the presence of repetitions in the REP sequences benefited learning, as testified by the comparison with the non-REP sequences, notably for older children.

Let us examine now separately the respective contribution of positional (first bigrams) and perceptual (repetitions, second bigrams) saliencies in the REP group performance, as compared with the non-REP group.

Sensitivity to correct salient units: Differential effects in the two learning groups?

Frequencies of production of correct salient units (first or second bigrams) as a function of group and age are presented in Figure 2. Student's t test revealed that the bigrams present in second position within the REP sequences (26.7%) were more reproduced at test than those present in the non-REP sequences (8.9%), $t(54) = 3.93$, $p < .001$, $d = 1.05$, while no difference between the REP and non-REP groups was revealed for the production of the first bigrams (respectively, 20.5% and 19.6%), $t < 1$. In the non-REP group, correct first bigrams were marginally inserted more often in the flags at test than the second bigrams, $t(28) = 1.86$, $p = .07$, $d = 0.57$, while it was not the case in the REP group, $t(28) = -1.37$, $p = .18$, $d = 0.30$. In the REP group, the 8-year-old children produced more correct first bigrams (32.1%) and more repetitions (35.1%) than the 5-year-olds (respectively, 8.9% and 18.4%), $t(26) = 3.26$, $p < .01$, $d = 1.23$, and $t(26) = 2.52$, $p < .05$, $d = 0.95$. By contrast, in the non-REP group, correct first bigrams (5 years: 16.1%; 8 years: 23.2%) and second bigrams (5 years: 6.5%; 8 years: 11.3%) were produced regardless of age, $t_s < 1$.

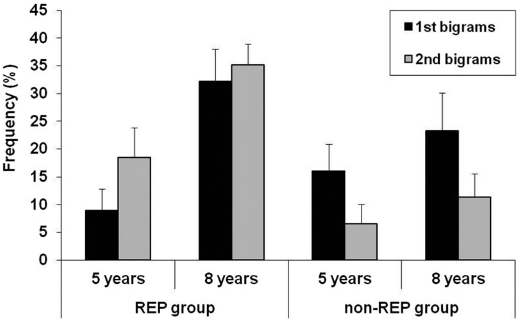

Figure 2. Mean frequencies of correct first and second bigrams (in the training sequences) produced at test as a function of group (2: REP or non-REP) and age (2: 5 years or 8 years). REP = repetitions, non-REP = no repetition. The error bars correspond to one standard error.

These results revealed that the second bigrams were better learned when reinforced by perceptual salience, giving an advantage to the REP group as compared to the non-REP group. Moreover, first bigrams tended to be better learned than second bigrams only when the latter were not perceptually salient, as was the case in the non-REP group as compared to the REP group. Furthermore, the above-pointed-out age effect, reported in the REP group only, concerned both the production of first and the production of second bigrams. The final question was whether children learned longer chunks as they grew up. We thus analysed the production of correct first trigrams at test.

Sensitivity to correct first trigrams: An advantage for older children ?

The learning of longer chunks was tested through the production of correct first trigrams. As depicted by Figure 3, a 2 (group) × 2 (age) ANOVA showed that the REP group produced more correct first trigrams (29.2%) than the non-REP group (3%), $F(1, 52) = 12.57$, $p < .01$, $\eta_p^2 = .19$, and that the 8-year-old children (25.6%) outperformed the 5-year-olds (6.5%), $F(1, 52) = 6.65$, $p < .05$, $\eta_p^2 = .11$. The Group × Age interaction was also significant, $F(1, 52) = 5.84$, $p < .05$, $\eta_p^2 = .10$. In the REP group, the 8-year-olds produced more correct first trigrams (47.6%) than the 5-year-olds (10.7%), $t(26) = 2.61$, $p < .05$, $d = 0.98$,whereas the 5- and the 8-year-olds in the non-REP group exhibited equal performances (respectively, 2.4% and 3.6%), $t < 1$.

The 8-year-olds thus developed sensitivity to the first trigrams only when they included a salient perceptual regularity, even though the second bigrams in the non-REP sequences were very frequent (see Table 2). We checked that the 8-year-olds in the non-REP group learned these frequent second bigrams (11.3%) better than all the other much less frequent bigrams present in the non-REP sequences (3.8%), $t(13) = 2.17$, $p < .05$, $d = 0.65$, thus confirming the well-known effect of frequency in incidental sequence learning. This suggests a particular role of perceptual salience in the early formation of larger chunks.

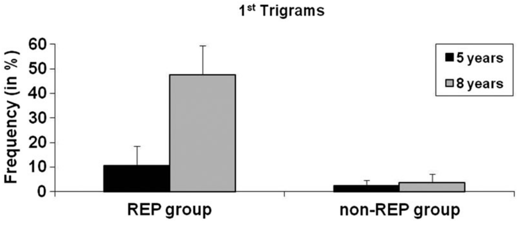

Figure 3. Mean frequencies of correct first trigrams (in the training sequences) produced at test as a function of group (2: REP or non-REP) and age (2: 5 years or 8 years). REP = repetitions, non-REP = no repetition. The error bars correspond to one standard error.

Provisional discussion

Experiment 1 suggested that perceptual and positional saliencies benefited learning and that repetitions permitted the formation of longer units (trigrams) in the oldest children. However, these conclusions rest on a single production from the participants. In addition, the task used at test, an explicit generation task, did not permit us to assess whether age-related performance resulted from age-dependent differences in the influences exerted by perceptual and positional saliencies or from more efficient intentional retrieval processes in older children than in younger children. In order to address these issues, a second experiment was run. In Experiment 2, incidental learning of the REP and non-REP sequences in 5- and 8-year-old children was assessed through a recognition task. Because recognition partly rests on a feeling of familiarity relating to implicit memory processes (Gardiner & Java, 1993), known to be robust to individual and contextual factors (Reber, 1993), more age-independent performance should be observed in Experiment 2 than in Experiment 1.

Experiment 2

Method

Participants

Eighty children (44 female and 36 male) participated in the experiment. Half of them were kindergarten aged 5 years ($N = 40$), and the other half were second graders aged 8 years ($N = 40$). Within each age group, the participants were randomly assigned either to the REP group ($N = 20$) or to the non-REP group ($N = 20$). Table 3 presents the characteristics of the groups.

Material

We employed the same computer game as that used in Experiment 1. The flags within the REP and the non-REP series remained the same. However, the incidental exposure phase was followed by a

Table 3. Characteristics of the groups enrolled in Experiment 2.

Age (years)	Mean age (years, months)	Sex	Group	*N*	Mean age (years, months)	Sex
5	5,6 (span: 4,11–5,11)	24F, 16M	REP	20	5,5	12F, 8M
			non-REP	20	5,7	12F, 8M
8	8,5 (span : 7,11–9)	20F, 20M	REP	20	8,3	10F, 10M
			non-REP	20	8,7	10F, 10M

Note: REP = repetitions; non-REP = no repetition; F = female; M = male.

recognition test instead of a generation test. To this end, six of the eight flags seen during the learning phase—2 three-colour flags, 2 four-colour flags, and 2 five-colour flags—were selected to instantiate "the flags that belonged to the pandas", and six new flags—2 three-colour flags, 2 four-colour flags, and 2 five-colour flags—were generated to instantiate "the flags that belonged to other animals". The six already-seen flags as well as the six new flags were selected as a function of different measures of associative chunk strength. These measures considered "*the frequency with which the bigrams and trigrams present in the test strings appeared in the learning strings*" (see Meulemans & Van der Linden, 1997, for details), so that test items in the REP and non-REP group did not differ regarding their associative chunk strength. In addition, the six new test items were built in order to test whether false alarms (say "*yes*" for a flag that did not belong to the pandas) were committed because they shared common bigrams, at first or second positions, with the learning items. An example of a test series for the REP-group was: six already-seen flags that belonged to the pandas, BYY–RGG–BYYR–RGGY–BYYTG–RGGBT; three new items sharing common first bigrams with the pandas' flags, **BY**G–**RG**BT–**BY**GBT; and three new items sharing common second bigrams with the pandas' flags, R**YY**–B**GG**Y–R**YY**TG. An example of a test series for the non-REP group was: six already-seen flags that belonged to the pandas, BYG–RBT–BYGR–RBTG–BYGTR–RBTGY; three new items sharing common first bigrams with the pandas' flags, **BY**T–**BY**TG–**BY**RBT; and three new items sharing common second bigrams with the pandas' flags, R**YG**–R**YG**T–R**YG**TR. The characteristics of the test series for the REP and the non-REP groups are presented in Table 4.

Procedure

The same incidental exposure phase as that described in Experiment 1 was followed by a 10-minute recognition phase. The recognition test was introduced with the picture of puzzled pandas in front of a flags' mound, accompanied with the following instructions: "*After the tournament, the pandas' flags were mixed with those of other animals. Help the pandas find their own flags!*" The children were presented with a first flag and listened to the following instruction: "*Is this a flag that you have already seen and that belonged to the pandas?*" The experimenter recorded the answers of the participants by pressing the keys corresponding to the choice of the children (left arrow = yes or right arrow = no), then the second flag was displayed automatically, accompanied with the same previous instruction, and remained visible until the child completed the question. This procedure repeated until the 12 flags were successively shown to the children. The order of appearance of the flags was random. The recognition phase ended with a short animation congratulating the child at the end of the game.

Coding of the data

We coded the number of correct responses, and we computed the frequencies of correct responses, the frequencies of hits (say "*yes*" for a flag that belonged to the pandas), and the frequencies of false alarms (say "*yes*" for a flag that did not belong to the pandas). In addition, two types of false alarms were considered: false alarms for the new flags (belonging to other animals) that embedded the same first bigrams as those in the pandas' flags, and false alarms for those that embedded the same second bigrams as those in the pandas' flags. ANOVAs with group (2: REP and non-REP) and age (2: 5 years and 8 years) as inter-subjects factors were carried out on the frequencies of correct responses, hits, and false alarms. We separated false alarms for test items that contained legal second bigrams or repetitions (FA2ndbig) from false alarms for items that embedded legal first bigrams (FA1stbig). This permitted us to investigate whether children became sensitive only to isolated bigrams seen during the learning phase (many FA for test items containing these units) or whether they formed larger chunks that

Table 4. Characteristics of the test items used in Experiment 2.

	"Panda"'s flags								New flags with same first bigrams									New flags with same second bigrams								
Test items	GBS	GTS	GCS	IB	IT	FB	FT	AP		GBS	GTS	GCS	IB	IT	FB	FT	AP		GBS	GTS	GCS	IB	IT	FB	FT	AP
For REP condition																										
BYY	4	4	4	4	4	1	1	1	BYG	2.5	0	1.7	4	0	1	0	1									
RGG	4	4	4	4	4	1	1	1	RGBT	2	0.5	1.4	4	0	1	1	2									
BYYR	3	2.5	2.8	4	4	1	1	1	BYGBT	1.8	0.3	1.1	4	0	1	1	2									
RGGY	3.3	3	3.2	4	4	1	1	1										RYY	2	0	1.3	0	0	1	0	0
BYYTG	2.5	2	2.3	4	4	1	1	1										BGGY	2	1	1.6	0	0	1	1	1
RGGBT	2.5	2	2.3	4	4	1	1	1										RYYTG	1.5	0.7	1.1	0	0	1	1	1
M	3.2	2.9	3.1	4	4	1	1	1		2.1	0.3	1.4	4	0	1	1	1		1.8	0.6	1.4	0	0	1	1	0
For non-REP condition																										
BYG	4.5	4	4.3	4	4	2	1	2	BYT	2	0	1.3	4	0	0	0	1									
RBT	4	4	4	4	4	1	1	1	BYTG	2	0	1.2	4	0	1	0	1									
BYGR	3.3	2.5	3	4	4	1	1	1	BYRBT	3	1.3	2.3	4	0	1	1	2	RYG	2.5	0	1.7	0	0	1	0	0
RBTG	3.3	3	3.2	4	4	1	1	1										RYGT	2.3	1	1.8	0	0	1	1	1
BYGTR	3	2.3	2.7	4	4	1	1	1										RYGTR	2	1	1.6	0	0	1	1	1
RBTGY	2.8	2.3	2.6	4	4	1	1	1																		
M	3.5	3	3.3	4	4	1	1	1		2.3	0.4	1.6	4	0	1	0	1		2.2	1	1.7	0	0	1	1	1
p-value	.7	.4	.6	—	—	1	—	1		.6	.7	.6	—	—	0	1	0		.1	.8	.1	—	—	—	1	1

Note: GBS = global bigram strength; GTS = global trigram strength; GCS = global chunk strength; IB = initial bigram; IT = initial trigram; FB = final bigram; FT = final trigram; AP = anchor positions; B = blue; G = green; R = red; Y = yellow; T = turquoise.

concatenated first and second bigrams (few FA since new test items never embedded legal first trigrams). We notably expected young children in the REP group to produce more FA2ndbig than FA1stbig, and young children in the non-REP group to produce more FA1stbig than FA2ndbig, while the older children should produce less FA than the younger ones, especially in the REP condition, which promoted learning of the first trigrams, as observed in Experiment 1.

Results

Recognition performance as a function of group and age

Incidental learning of the REP and non-REP sequences as a function of age was assessed through the frequencies of correct responses during a recognition test. The results are presented in Figure 4.

ANOVA with group (2: REP and non-REP) and age (2: 5 years and 8 years) on the proportion of correct responses revealed a significant effect of group, $F(1, 76) = 3.78$, $p = .05$, $\eta_p^2 = .05$, with the non-REP group (63.9%) outperforming the REP group (57.3%), and a marginal effect of age, $F(1, 76) = 3.32$, $p = .07$, $\eta_p^2 = .04$, with the 8-year-old children tending to show a better recognition performance (63.7%) than the 5-year-old children (57.5%). In addition, we observed a significant Group × Age interaction effect, $F(1, 76) = 3.78$, $p = .05$, $\eta_p^2 = .05$, with the 8-year-olds (63.7%) outperforming the 5-year-olds (50.5%) in the REP group, while the two age groups performed equally in the non-REP group (5 years = 64.2% ; 8 years = 63.7%). Analysis on the d' criteria (hits – false alarms) confirmed these results (group effect, $p = .05$, age effect, $p = .07$, Group × Age, $p = .05$).

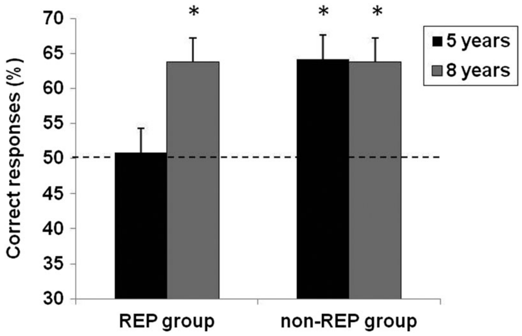

Figure 4. Mean frequencies of correct responses produced at test as a function of group (2: REP or non-REP) and age (2: 5 years or 8 years). REP = repetitions, non-REP = no repetition. The error bars correspond to one standard error, the hatched line represents chance level, and asterisks indicate performance significantly above chance.

Student's t tests were carried out to compare the frequencies of correct responses with chance (50%). As shown by Figure 4, the oldest children performed above chance in the recognition task, whatever the group: REP (63.7%), $t(19) = 3.83$, $p < .01$, $d = 1.21$; non-REP (63.7%), $t(19) = 3.83$, $p < .01$, $d = 1.21$, while only the younger children in the non-REP group (64.2%) performed significantly above chance, $t(19) = 4.67$, $p < .001$, $d = 1.48$. The 5-year-olds performed at chance level in the REP group (50.8%), $t < 1$.

Because quantitative differences of performance did not systematically emerge between the REP and the non-REP groups, we pursued our analysis to test whether more qualitative differences existed between the REP and the non-REP group.

Qualitative differences in the acceptation and rejection of the test items

A 2(group) × 2(age) ANOVA was run on the frequencies of hits in order to assess the children's propensity to accept the pandas' flags during the recognition task. We failed to show any group, age, or Group × Age interaction effects, respectively, $F < 1$, $F < 1$, and $F(1, 76) = 1.36$, $p = .25$. These results suggested that the better performance of the non-REP group in the younger children did not rest on the acceptation of previously seen flags.

Because two types of new flags were built, some containing the same first bigrams and others containing the same second bigrams as the pandas' flags, analyses were run separately on the two types of false alarms committed on test items: respectively, FA1stbig and FA2ndbig.

A 2 × 2 ANOVA on the frequencies of FA1stbig revealed a significant effect of age, $F(1, 76) = 11$, $p < .001$, $\eta_p^2 = .13$, with more FA1stbig in the 5-year-olds (56.7%) than in the 8-year-old children (34.2%), while the group and the Group × Age interaction was not significant, $F_s < 1$. Analysis on the frequencies of FA2ndbig reported a significant effect of group, $F(1, 76) = 5.33$, $p < .05$, $\eta_p^2 = .07$, with the REP group (57.5%) committing more FA2ndbig than the non-REP group (40.8%). Age failed to yield a significant effect, $F(1, 76) = 2.61$, $p = .11$. However, a just significant Group × Age interaction effect, $F(1, 76) = 3.4$, $p = .05$, $\eta_p^2 = .04$, indicated that the 5- (40%) and the 8-year-olds (41.7%) in the non-REP group equally produced FA2ndbig, while the 5-year-olds (70%) produced much more FA2ndbig than the 8-year-olds (45%) in the REP group.

In sum, the low performance of the 5-year-old children in the REP group resulted from the difficulty to reject new flags that embedded the same salient repetitions as those contained within the pandas' flags. This result did not necessary indicate that the younger children were more sensitive to repetitions than the older ones, but rather that they were, at best, equally sensitive to repetitions while they did not learn trigrams contrary to their older counterparts, which would have permitted them to reject FA2ndbig. They also committed many FA1stbig, showing that they became sensitive to first bigrams and repetitions but that they did not learn the trigrams. In the non-REP condition, the 5-year-old children did not commit many FA2ndbig but they committed more FA1stbig than the 8-year-old children, indicating that they became sensitive to the first bigrams but not to the second bigrams. Finally, the oldest children committed few FA, less frequently than the younger children, suggesting that they learned larger units, trigrams, containing both first and second bigrams.

General discussion

The present experiments aimed to investigate the role of perceptual and positional saliencies in the early formation of chunks during incidental learning of sequences in children of different ages. We tested their respective contributions in the learning of sequences that all embedded positional saliencies (REP and non-REP sequences), but only some of which contained repeated elements (REP sequences). While Experiment 1 assessed performance with an explicit generation task at test, a recognition task was used in Experiment 2. The discussion focused on how perceptual and positional saliencies affected the performance differentially with age as a function of the instructions used at test.

Perceptual, positional, and statistical information in the initial formation of chunks

Experiment 1 showed that despite equal frequencies, the perceptually (repetitions) or positionally (initial bigrams) salient units were preferentially learned, compared to units devoid of these two saliencies (second bigrams in the non-REP sequences). Using a recognition task, Experiment 2 suggested that children became sensitive to both perceptually and positionally salient units, while the younger children did not develop sensitivity to units that only benefited from statistical salience (second big in the non-REP condition).

These results are congruent with our assumption that sources of information other than statistical may influence sequence learning. They also corroborate previous studies that have reported the benefits derived from the learning of repeated elements (Monaghan & Rowson, 2008), as well as of the initial and final units of sequences (Conway & Christiansen, 2009). Perceptual and positional saliencies thus seem to provide stronger guidance than frequency alone in the early learning of chunks. This is consistent with Perruchet and Pacton's (2006) suggestion that the formation of chunks may both precede and help bring about sensitivity to statistical structure. However, the performance based on the formation of initial chunks may differ as a function of age and instructions used at test.

Generation task versus recognition task to assess incidental initial formation of chunks

Experiment 1 reported that sensitivity to positional salience operated regardless of age in the non-REP group, whereas sensitivity to repetitions, as well as to positional salience, was age dependent in the REP group. In contrast, Experiment 2 suggested that sensitivity to repetitions and positional salience was age independent.

In accordance with our predictions, performance appeared more robust to age when learning was assessed with a recognition task that partly elicited implicit memory processes (Experiment 2), instead of a generation task that mainly required intentional explicit retrieval processes of information (Experiment 1). In addition, as mentioned in a footnote (Footnote 4), visual search and selection of the coloured squares during the generation task (Experiment 1) may have caused higher memory demands in the younger than in the older children, making this task more age dependent than the recognition task (Experiment 2). Because the learning phase was strictly the same between the two experiments, the age-related differences could not be attributed either to differential complexity of the learning material or instructions (e.g., Howard & Howard, 1997), or to differential underlying knowledge elicited by the task (Murphy, McKone, & Slee, 2003; Perez, Peynirciolu, & Blaxton, 1998). They could rather be due to how test instructions made the procedure more or less permeable to explicit influences (Meulemans, 1998; Vinter & Perruchet, 1999). This hypothesis was recently tested in an experiment that reported that age-independent performance with implicit test instructions turned age dependent when more explicit test instructions were employed at test (Witt et al., 2013). The authors also observed that the oldest children were able to learn trigrams, while younger children failed to learn chunks larger than bigrams. Similar results were observed in the present experiment.

The formation of larger chunks: The role of individual factor

Another interesting result concerned the fact that the young children did not learn trigrams, while the oldest children did. We hypothesized that the greater attentional capacities of the 8-year-old children than of the 5-year-olds should enable the older children to form larger chunks (Cowan, 2000; Oberauer, 2002). The fact that the 8-year-olds built larger chunks than the younger children is in line with the results reported by Cowan, Morey, AuBuchon, Zwilling, and Gilchrist (2010). These authors indicated that working memory capacity, mediated by attentional resources, increased noticeably from 7 years to adulthood, with the number of items that participants could store growing from 1.5 at 7 years of age to 3 in older children and adults. Thus, developmental changes were observed when performance was assessed through the formation of more complex (larger) chunks. Further evidence corroborating these results comes from studies reporting the effects of interactions between contextual and individual factors on implicit learning performance. For instance, effects due to the complexity of the material have been reported in adults (Soetens, Melis, & Notebaert, 2004; Stadler, 1992) as well as in the elderly, with the oldest participants learning less as complexity increased (Bennett, Howard, & Howard, 2007). Developmental changes in implicit learning performance have also been observed and have been attributed to the structural complexity of the material as well as to the age-related evolution of the knowledge base required in order to cope with the learning task (Murphy et al., 2003; Witt et al., 2013). However, we can also ask whether the younger children might have achieved performances equal to those of the oldest participants if they had benefited from additional exposure, as has been reported in a previous study (Thomas et al., 2004). Indeed, some studies using an artificial grammar learning paradigm have reported that a longer period of exposure to the material is necessary in order for participants to learn higher order dependencies than for the learning of first- or second-order dependencies (Meulemans & Van der Linden, 1997). This empirical question would seem to deserve further investigation.

The formation of larger chunks: The role of contextual factors

A last interesting result concerned differential contextual effects, REP versus non-REP conditions, as a function of the instructions used at test. The oldest children actually learned the initial trigrams when they included salient adjacent repetitive information (REP group) in Experiment 1. We consider that this positive learning of the initial salient trigrams prevents to interpret separately the learning advantage of the REP group over the non-REP group with regard to the first and second initial bigrams, necessarily included in the trigram. However, Experiment 2 suggested that initial trigrams were potentially learned regardless of the REP and non-REP conditions. In other words, the oldest children were able to learn trigrams even when they did not include a salient adjacent repetition.

Within the REP sequences, the particular salience of repetitive information might have caused the children to consider repetitions as perceptual primitives that could be concatenated with recurrent adjacent elements. Indeed, from an associative viewpoint (Mackintosh, 1975), three elements, of which two are similar (e.g., BYY), are more easily connected than three distinct elements (e.g., BYG). The participants might need longer exposure time to the initial trigrams in the non-REP conditions for the latter to be consolidated as chunks. The time used in Experiments 1 and 2 might have been sufficient for the emergence of a fluency heuristic, appropriate in a recognition task, but not for eliciting strategic recollection processes needed in the generation test (e.g., Kinder, Shanks, Cock, & Tunney, 2003). In the same vein as we can ask whether the younger children might have perform equally to the oldest children with additional exposure (Thomas et al., 2004), we can also ask whether the non-REP group would benefit from extended exposure to learn and generate larger chunks. Further investigation should address this empirical question.

Conclusion

In conclusion, the present experiment reported evidence that initial segmentation and hierarchical learning are influenced by multiple factors, such as the relative salience of the input signal and the individual's attentional capacities. Kruschke (2010) suggested that if attention plays a role in associative learning, then salience should have an effect on this type of learning, since salience is defined as the ability to attract attention. In this line of reasoning, our results confirm that attention is involved during an incidental learning episode (Jiménez & Méndez, 1999; Tanaka, Kiyokawa, Yamada, Dienes, & Shigemasu, 2008). More precisely, the presence of amplification and attenuation effects operating on local parts of the input signal is coherent with the involvement of "selective" attention processes during implicit learning (Larrauri & Schmajuk, 2008; Rowland & Shanks, 2006). The more salient a feature is, the more likely it is to attract attention and consequently to create a cognitive unit (Perruchet & Vinter, 2002). Salience effects (especially those related to adjacent repetitions) appear to influence the incidental discovery of the learning material during its early segmentation and at some stages during the formation of more complex units, although the effects appear to differ with age and as a function of the procedure used to assess sequence learning. The role of other types of perceptual salience in sequence learning should be investigated in further studies, in particular with regard to non-adjacent repetitions or symmetry (Pornstein & Krinsky, 1985; Wenderoth, 1994), or by using a combination of perceptual and positional cues (Endress, Scholl, & Mehler, 2005).

Notes

1. If chunking generally refers to a strategy that we intentionally use in daily situations for reducing cognitive demands in various tasks (to concatenate digits in a series of numbers to learn and remember a phone number, for instance), chunking is also considered *as a mechanism of implicit learning*. As claimed by Perruchet (2008, p. 608), "*the fact that implicit learning leads to the formation of chunks is largely consensual*". However, there are two ways to consider chunking in the domain of implicit learning (see Perruchet & Pacton, 2006, for a discussion). First, chunks could be inferred from the statistical distribution of the material (e.g., Saffan & Wilson, 2008). Second, chunks could emerge without prior statistical computations. The initial formation of chunks could be guided by prior knowledge or sensitivity to salient features, for instance, but only chunks consistent with the statistical structure of the environment are consolidated and become relevant cognitive units (Perruchet & Vinter, 2002; Servan-Schreiber & Anderson, 1990). The present paper thus aimed to investigate the sources of information that contributed to the incidental formation of chunks.
2. The choice of the fifth colour, turquoise, may seem curious. However, preliminary investigations revealed that turquoise was a good candidate compared with other alternatives. Black and white colours were rejected because these colours within the sequences were interpreted as errors or omissions of colours by the children and thus elicited their attention in a problematic manner. Other secondary colours were judged less attractive than primary colours by children and potentially "under-selected" in consequence during the generation task. As a precaution, we limited the possibility to present blue and turquoise as consecutive/adjacent colours within the sequences, especially at the beginning of the flags. However, this case could not be totally excluded since we aimed to present each child with a different instantiation of the series to prevent any order effect of colour presentation.
3. The number of flags of three, four, and five colours was estimated in order to compose a 20-minute learning phase with some repetitions of each flag. The length of the flags was inspired by previous studies in adults and children using letter strings that contained generally two to five letters. However, three-colour strings were the minimal length for investigating competitive chunking between the first and second bigrams of the sequences. In addition, only two legal first bigrams and two legal second bigrams were authorized in the REP or in the non-REP sequences. So it was possible to generate only 2 three-colour strings for each condition, REP and non-REP, while more possibilities were offered in the production of the four- and five-colour strings.
4. An anonymous reviewer pointed out the possibility that the use of 25 coloured squares during the generation task might have disadvantaged the younger children, increasing visual search demands and the time needed to reproduce flags, thus imposing higher memory demands to young children during the generation task. For this reason, and others mentioned latter in the manuscript, Experiment 2 introduced a recognition task, less demanding in cognitive resources and therefore more age independent.
5. Readers may wonder whether this task can be truly considered as "incidental" since the attention of the participant is drawn to the flags by the following instructions: "*the pandas will show you their pretty flags*". Because implicit learning was first defined as an automatic learning process, in opposition with controlled processes of explicit learning, "implicit" and "attention" are usually considered mutually exclusive terms. However, a growing body of evidence shows that selective attention is involved, and is necessary, during an implicit learning episode (e.g., Hoffmann & Sebald, 2005; Hsiao & Reber, 1998; Jiménez & Méndez, 1999; Pacton & Perruchet, 2008). The fact that the instructions referred to the flags was not a problem per se. The only characteristic to

meet is that "*implicit learning proceeds without participants' intention to learn*" (Perruchet, 2008).

6. The scoring procedure did not take positional constraints into account mainly because positional information may not be learned in the case of micro-rules learning, incomplete exemplars (possible in a brief exposition), or fragments/chunks learning. Position is therefore not a decisive argument to assess implicit learning of chunks, which is what we precisely investigated in our study. In addition, a fragmentarist view would predict that fragments in salient positions (at the beginning of the sequences, for instance), which intrinsically embed positional information, would be advantaged by a scoring procedure with positional constraints, while the fragments in non-salient positions (second bigrams for instance) would be disadvantaged (e.g., Perruchet, 1994), making unfair the evaluation of competitive chunking between these units. Though the scoring procedure did not consider positional constraints, sequences with positional constraints were, however, preferred because positional salience was one of the type of saliencies we aimed to study. It is indeed very likely that fixed positions favour the detection of regularities and facilitate implicit learning processes (e.g., Mathews et al., 1989).

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