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Article type : Paper

Title: **Children's scale errors: A by-product of lexical development?**

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Acknowledgements

This work was funded by a Marie Curie Intra-European Fellowship within the 7th European Community Framework Programme (ORATOR FP7-PEOPLE-2012-IEF). The authors would like to thank Paul Ratnage and Jodie McLoughlin for help in collecting the data, and parents and their children for their participation in the study.

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record. Please cite this article as doi: 10.1111/desc.12741

Research Highlights:

- Scale errors linearly decrease with age in childhood
- Scale errors are more likely to be found in early talkers
- Scale errors are not a stage in development
- Individual variations may relate to the speed of development of the linguistic and conceptual systems

Abstract

Scale errors occur when young children seriously attempt to perform an action on an object which is impossible due to its size. Children vary substantially in the incidence of scale errors with many factors potentially contributing to these differences, such as age and the type of scale errors. In particular, the evidence for an inverted U-shaped curve of scale errors involving the child's body (i.e., body scale errors), which would point to a developmental stage, is mixed. Here we re-examine how body scale errors vary with age and explore the possibility that these errors would be related to the size and properties of children's lexicon. A large sample of children aged 18 to 30 months (N = 125) was tested in a scale error elicitation situation. Additionally, parental questionnaires were collected to assess children's receptive and expressive lexicon. Our key findings are that scale errors linearly decrease with age in childhood, and are more likely to be found in early talkers rather than in less advanced ones. This suggests that scale errors do not correspond to a developmental stage, and that one determinant of these errors is the speed of development of the linguistic and conceptual system, as a potential explanation for the individual variability in prevalence.

Key words: scale errors, lexical development, conceptual development, object representation, early talkers

Child studies have consistently reported that young children make scale errors, that is, they seriously attempt to perform an action on an object which is inappropriate because of the object size (e.g., Brownell, Zerwas, & Ramani, 2007; Casler, Eshleman, Greene, Terziyan, 2011; DeLoache, Uttal, & Rosengren, 2004; Ware, Uttal, Wetter, & DeLoache, 2006). Scale errors may refer to children's actions on an object that is inappropriately scaled (generally too small) to accommodate for their body (i.e., body scale errors). Examples of body scale errors include children attempting to sit in a tiny chair, slide down a miniature slide or get inside miniature toy cars (e.g., DeLoache et al., 2004). Scale errors may also refer to actions in which children use an object to act on another object that has an inappropriate size (either too small or too big) to be effective (i.e., tool/object based scale errors). Examples include children's attempts to put a doll into a bed that is too small to accommodate the doll's size (Ware, Uttal, Wetter, & DeLoache, 2006), or children's attempts to use a net for scooping fake fish that is too big to fit into the aquarium (Casler, Eshleman, Greene, & Terziyan, 2011).

Children vary substantially in the incidence and perseveration of scale errors with many factors potentially contributing to these differences (Rosengren, Carmichael, Schein, Anderson, Gutierrez, 2009; Rosengren, Schein & Gutierrez, 2010). The aim of this paper is to re-examine the impact of age on the prevalence of scale errors involving the child's body, and to test for the possibility that they would be related to the development of word knowledge.

In the seminal work by DeLoache et al. (2004), the number of body scale errors followed an inverted-U shape function of age of three groups between 18 and 30 months (low at 18- to 20; high at 20.5 to 24; and low at 24.5 to 30 months). Similar inverted U-shape trend was reported in a study examining parents' reports of everyday scale errors, showing an early onset at 12 months, a peak at around 20 – 24 months and a decrease by 30 months followed by a disappearance at 36 months (Ware, Uttal, & DeLoache, 2010). Rosengren et al. (2009) investigated the incidence of scale errors in three groups of children at 11 months intervals between 4 and 40 months of age, showing again an inverted U-shape. However, some of young children included in the sample were not yet mobile, therefore unable to interact with the full-sized toys used in the study (e.g., slide, sofa or rocking chair). After removing those infants in the age range of 4-16 months, Rosengren et al. (2009) reported a decrease in the production of scale errors from infancy to 40 months. However, it must be noted that the wide age range of the middle toddler group (17 to 28 months) spanned over the three age groups tested by DeLoache et al. (2004), possibly masking the chance to see the inverted U-shape. Finally, Brownell et al. (2007), in their assessment of body self-awareness in young children, used scale errors scenario as one of the three tasks that measured children's understanding of their body size in relation to the external objects. Here again, no inverted U-shape change was found, as children's errors gradually decreased between 18 and 26 months.

Given these inconsistencies, the first aim of this paper will be to clarify the link between age and the incidence of body scale errors between 18 and 30 months, an age range which appears to be critical for observing an inverted U-shaped curve (Deloache et al., 2004; Ware et al., 2010). While all studies have consistently reported that these errors decrease by 30 months (Brownell et al., 2007; DeLoache et al. 2004; Rosengren et al., 2009), it remains unknown whether the function takes an inverted U-shape function of age as reported in DeLoache et al. (2004) and Ware et al. (2010), or decreases linearly as in Rosengren et al. (2009). The occurrence of U-shape function may sometimes represent a "methodological artifact" sensitive to the sample size and concentration of values across the entire age range (Pauls, Macha, & Petermann, 2013).

The shape of the function of scale errors with age has important implications for identifying the potential mechanism underlying this phenomenon. In developmental terms, a decreasing linear function would point to a maturation process linked to any number of developing concurrent abilities (working memory, object representation, body knowledge, inhibitory control, etc.) (Siegler, 2004). In contrast, an inverted U-shaped function would point to scale errors being a *stage* experienced by all typically developing children; it would also put greater constraints on the underlying mechanism as any potential mechanism would have to explain an initial rise and subsequent fall in performance (Siegler, 2004).

Although there is a general consensus that scale errors result from children's weak inhibitory control that fails to suppress automatic motor responses (Brownell et al., 2007; Casler et al., 2011; DeLoache et al., 2004), the explanations vary on the nature of the different cognitive processes involved in action planning that could result in such errors. According to DeLoache et al. (2004), they reflect a dissociation between the action planning system (or the ventral pathway, e.g. Goodale & Milner, 1995) and the action control system (or dorsal pathway). Upon seeing a miniature object, such as a tiny chair, the ventral system computes an action plan based on the features of the object (e.g. shape, colour), leading to the selection of an action plan compatible with a prototypical object (e.g. sitting). The dorsal system, which controls movement, should then inhibit the selected action plan based on incompatible size information, but fails to do so because of the child's weak inhibitory control, leading to a scale error. Such mistakes could possibly result from rapid developments in conceptual representations of object categories during the second year of life (Mandler & DeLoache, 2012): the view of a small object from a familiar category activates the increasingly complex object representation that could sometimes override perception of its size. Casler et al. (2011) elaborates further DeLoache's et al. (2004) explanation and suggest that the neglect of size in perception results from a strong association between the object representation and its function (i.e., teleofunctional bias), whereby seeing a miniature object activates the typical function of an object even though a particular item has a clearly inappropriate size. Finally, Brownell et al. (2007) also assumes that scale errors are caused by an immature representational system, but attribute it on impoverished representations of children's own body rather than problems with object representations. In this perspective, children's action planning processes fail to incorporate or access the information about their body size, generating inappropriate actions when the size of the object and that of the body do not correspond.

Overall, these explanations seem to be linked to developmental changes in the conceptual system, and point to an unexplored potential factor behind individual differences in the children's production of scale errors, that is, the child's lexical development. The second year of life is characterized by a noticeable acceleration in word acquisition (McMurray, 2007), that accompanies developments in other domains such as object perception, recognition and representation, motor development, and action on object (Smith, 2013). Object name learning has important consequences for object perception, as it may lead children to attend primarily to shape information and possibly neglect other physical features such as colour, texture, and more importantly here, size (Landau, Smith, & Jones, 1988; Samuelson & Smith, 2000; Yoshida & Smith, 2005). The well-established increased attention to object shape between 18 and 30 months (i.e., shape bias; Landau, Smith, Jones, 1988) has been found to be developmentally related to the children's vocabulary size, emerging when children have between 51 and 100 object names in their productive vocabularies (Gershkoff-Stowe & Smith, 2004; Smith, 2003). Similarly, children with a larger number of object names in their productive vocabulary are better than their peers at recognizing objects when only shape information is provided (with a high degree of local detail), but no information about colour or texture (Pereira & Smith, 2009). Importantly, children who are significantly behind their peers in terms of expressive lexicon size, *late talkers*, show no perceptual shape bias in a novel object name extension task; instead, they extend novel names to objects with the same surface texture (Jones, 2003). They are also delayed in the recognition of abstract forms (Jones & Smith, 2005). Overall, this suggests that learning of an object name changes some aspects of object perception and representation, which may in turn modify the way children act on the object, possibly modulating the incidence of scale errors.

If there is a link between scale errors and knowledge of objects names, one could expect first that linguistic cues that direct attention to the identity of objects might boost the incidence of scale errors. Indeed, when objects are labelled, the incidence of scale errors in tool-based scale errors scenario increases compared to a non-labelling condition (Hunley & Hahn, 2016). In addition, Oláh, Elekes, Pető, Peres and Király (2016) showed that children were more likely to produce scale errors with tools when object labels were introduced in children's native language as opposed to a foreign language, suggesting that meaningful linguistic information is needed for this facilitation to occur - at least in situations where children are required to act with tools.

Therefore, the second aim of this paper is to examine the relation between lexical development and the prevalence of scale errors, which generates three different hypotheses. First, based on findings that changes in object perception and representation relate to the number of object names in the expressive lexicon (Gershkoff-Stowe & Smith, 2004; Pereira & Smith, 2009; Yee, Jones, & Smith, 2012), we hypothesize that vocabulary size and the proportion of object names may be predictive of children's likelihood to produce scale errors. Early talkers may perform more scale errors than late talkers, as they may have developed more sophisticated object representations and subsequent perceptual biases such as shape bias. Similarly, children who command more concrete nouns might produce more scale errors than those who do not, again because of a head start in the development of perceptual biases.

Second, it is possible that the knowledge of specific words drives children's production of scale errors, rather than the overall size of the lexicon or the speed of acquisition. Gershkoff-Stowe and Smith (2004) reported that children's early vocabulary, including their first 25 words, is largely dominated by words referring to categories of things similar in shape (e.g. car, cup), which could explain the origin of the development of the shape bias in early childhood. Similarly, it could be that the way information about object size is encoded in the early lexicon relates to children's production of scale errors. To examine this hypothesis, we collected ratings of early words in terms of size similarity, as Gershkoff-Stowe and Smith (2004) did for shape, and examined if children's individual knowledge of these words relates to their production of scale errors. Here we supposed that the likelihood of producing scale errors would be inversely correlated to the knowledge of size-based nouns: the more size-based nouns would be learned, and the less likely children would commit scale errors.

Finally, it could be that the propensity to do scale errors increases with the development of the shape bias: the more children attend to shape, and the less they would pay attention to size, therefore resulting in more scale errors. Since it has been established that the shape bias grows noticeably when children produce between 51 and 100 words (Gershkoff-Stowe & Smith, 2004), we examined whether children producing between 51 and 100 words also tend to produce more scale errors than those who know less words.

Method

This study attempts to replicate the original findings as per DeLoache et al. (2004) study (N = 54), while recruiting a larger sample of children (N = 125), spanning the entire age range between 18 and 30 months. In order to investigate the links between age, the growth of the lexicon, and the incidence of scale errors, a representative estimate of the child's expressive and receptive vocabulary was collected through parental questionnaires.

Participants

One hundred twenty five children (*M* = 23.50, range = 18 to 29.7 months; including 55 girls) living in the South-West of the UK were recruited through the Babylab database. All children were monolingual English speakers, able to walk independently and were healthy and developing normally. As is the case in most lab-based studies, they all came from middle- to higher-class families. Several additional children were recruited, but their data could not be used for various reasons: they were born preterm (*N* = 3), they were fussy and refused to play with full-sized toys (*N* = 4), or there was an experimenter's error in the procedure (*N* = 1).

Stimuli

Stimuli for this study included three large play objects: an activity gym with a slide (128 x 76 x 76 cm) that children could climb up and slide down, two child-sized chairs (49.5 x 24.5 x 19.0 cm) that they could sit in, and a toy car (74.9 x 41.9 x 85.1 cm) that they could get inside and propel around the room with their feet. We also used three miniature replicas that were identical to their larger counterparts except for size: activity gym (24.3 x 12.7 x 15.24 cm), a chair (6.0 x 5.5 x 6.5 cm) and toy car (15.24 x 7.62 x 16.51 cm). Figure 1 presents the toys and their miniature replicas.

Vocabulary estimates

The Oxford Communicative Development Inventory (OCDI) was used to assess vocabulary development (Hamilton, Plunkett, & Schafer, 2000). This parental questionnaire is normed for British English speaking monolingual children's receptive and expressive vocabulary between the ages of 8 to 25 months.

Procedure

Prior to the beginning of the scale error study the parent was asked to fill in the OCDI. The child was observed in a laboratory play room where she or he was allowed to play naturally with the three child-size toys (a chair, a slide, and a car). In the beginning of the experimental session, the parent was instructed not to comment on the size of the objects. The child was encouraged to play with each of the three toys by the experimenter saying, for example, "Do you want to go on the slide?" or "Look at these chairs. Do you want to play with them?" After about 5-7 minutes of play, the child was escorted from the play room, and the large target objects were replaced with their miniature counterparts, without the child knowing. Then, the child was invited again to the room. If the child did not spontaneously interact with the replica objects, the researcher drew the child's attention to them by saying, for example, "Look at the slide", "Where are the chairs?" but without commenting on their size and without suggesting any interaction with the object. This phase lasted for another 5-7 minutes. Before leaving the room, the child was shown again the original toys, to prevent any potential signs of distress. All sessions were videotaped.

Coding

A scale error was counted for any instance of a behavior where the child seriously attempted to perform with a miniature object an action typically associated with its larger version. Only serious (not pretend) efforts to carry out the behavior were taken into account. Particularly clear signs of serious attempts were persistence in trying to carry out the impossible action, and cases in which children fell off the object while trying to perform an action on it, or requests for help from adults.

All sessions were independently recoded for reliability; inter-coder agreement was high (*Kappa* = .831, $p<.001$). After the reliability check, for any disagreements found both coders had to agree on the incidence of scale errors for the event to be included.

Results

The coding process identified 104 scale errors (31 with the chair, 53 with the slide, and 20 with the car), giving an average of 0.83 errors per child (*SD* = 1.36). There was no difference in the incidence of scale errors in boys (*M* = .80, *SD* = 1.25) and girls (*M* = .86, *SD* = 1.51), $t(123) < 1$.

Out of 125 children, 48 (38.4%) performed at least one scale error. Nearly half of the scale errors performers (N = 22) made only one error, and one child made as many as 7 errors (see Table 1). An independent samples Kruskal-Walllis test with age as DV and number of SE (from 1 to 7) as IV yielded no significant age differences across scale error frequency groups (p = .226, n.s.). Similarly, an independent samples Kruskal-Wallis test with CDI score as DV and number of SE as IV, yielded no significant differences in receptive (p = .658, n.s.) and expressive vocabulary (p = .620, n.s.) across scale error frequency groups. The effect of gender on error frequency could not be computed because of missing cells. Individual differences in the persistence of scale errors are likely to be caused by factors other than age and size of the vocabulary.

Prevalence of scale errors across ages

To answer our first question related to the existence of an inverted U-shape curve, we divided children into three age groups as in DeLoache et al. (2004): Group 1 (from 18 to 20 months; *N* = 21), Group 2 (from 20.5 to 24 months; *N* = 51) and Group 3 (from 24.5 to 30 months; *N* = 53). Mean number of scale errors per age group is shown in Figure 2. A Kruskal-Wallis test with number of scale errors per child as DV and age group as IV was significant (H (2) = 8.297, p = .0158), revealing that at least two age groups differed from each other. However, as Figure 2 illustrates, the incidence of scale errors decreased linearly with age and did not reveal any inverted U-shaped curve. The youngest group of children produced significantly more scale errors than the eldest group, (H (1) = 6.431, adjusted for multiple comparisons: p = .0112). No other comparison was significant.

Because the average of scale errors could be inflated by individual variability, we calculated in each age group the proportion of children who performed at least one scale error out of the total number of children. The difference between the proportion of scale errors children in the three age groups was significant (X^2 (2) = 13.498, p = .00117). Again, like in the average number of scale errors, the proportion of scale error children decreased with age. As Figure 3 illustrates, the proportion of scale errors children in Group 1 was significantly larger than in Group 3 (X^2 (1) = 11.622, adjusted for multiple comparisons p = .00065) as well as the proportion of scale errors children in Group 2 as compared to Group 3 (X^2 (1) = 8.054, adjusted for multiple comparisons p = .0045). The difference between Group 1 and Group 2 was not significant.

To examine the effect of age as a continuous variable, we conducted a logistic regression analysis to predict the occurrence of scale errors (none or at least one) using age (in days) as a predictor. The model was statistically significant, indicating that age distinguished between children who produced a scale error and those who did not (X^2 (1) = 4.44, p = .035). Prediction overall was 60.4% accurate (77.4% for non-scale error performers and 39.5% for scale error performers). The Wald criterion indicated that age negatively predicted scale errors (p = .039), with Exp(B) showing that as children got one day older, they were 0.994 less likely to produce a scale error. This analysis confirms that the likelihood to perform scale errors decreases linearly with age.

In what follows we examined the three hypotheses linking scale errors and lexical development, testing whether: (1) they could be found more often in early talkers than late talkers, and also in children who command a larger proportion of object names; (2) scale errors would depend on the knowledge of specific words, increasing as children learn more shape-base words and decreasing as they learn more size-based words; and (3) scale errors would be predominantly found in children know produce between 51 and 100 words.

Hypothesis 1: Relationship between scale errors and vocabulary size

To address whether the size of children's lexicon modulates the likelihood of scale errors, we only considered the group of children within the age range of the OCDI norms, that is, 25 months and younger. From our sample of children (N = 125) we retained data of the 96 children in the target age range (M = 22;31, range = 18;00 to 25;80, including 53 girls). The total receptive vocabulary of children who made at least one scale error (M = 271.7, SD = 98.2) was not different from that of children who did not make any scale errors (M = 272.7, SD = 106.2), $t(94) <1$. Similarly, for expressive vocabulary, no difference was found between scale error children (M = 163.8, SD = 98.2) and no-scale errors children (M = 154.2, SD = 106.2), $t(94) <1$. This indicates that both groups of children, scale errors or non-scale errors performers, are broadly comparable in terms of vocabulary.

Therefore we examined next whether children who are more advanced (or behind) in their overall vocabulary size as compared to their peers were more (or less) prone to make scale errors. From the OCDI norms, we categorized the children as being 'early', 'on-time' or 'late' in their overall vocabulary using the OCDI norms. Children with vocabulary size above 75th percentile for their age were part of the 'early' group, those who scored between 25th and 75th percentile were assigned to the 'on-time' group, and finally those who scored below 25th percentile to the 'late' group. We examined receptive and production vocabulary separately. Table 2 provides the number and ages of children in each vocabulary group.

The proportion of children who performed scale errors did not differ across the three groups for receptive vocabulary, $X^2(2) = 5.23$, $p = .073$, but differed for expressive vocabulary, $X^2(2) = 8.75$, $p = .013$. The Early talkers made more scale errors than the Late talkers (adjusted for multiple comparisons, $p = 0.03$); no other comparison was significant.

Because the group of Early talkers is younger than the group of Late talkers (see Table 2; $t(46) = 3.24$. $p = .002$), it is difficult to determine whether the scale error difference is related to age or vocabulary development. Therefore we matched the 23 Early talkers with 23 age-equivalent children from the rest of the cohort. These children were aged 638.6 days (STD 52.4) against 639.0 days (STD 53.2) for the Early talkers. Their mean expressive vocabulary was 73.1 words (STD 83.1) against 217.9 words (STD 99.3) for the Early talkers. Again, the proportion of scale error children was significantly larger in the Early talkers group (69.6%) than in the age-matched group (39.1%, X^2 (1) = 4.29, p = .038).

To examine whether children's scale errors relate to the proportion of object names they understand or say, we examined whether the three vocabulary groups (Early, On-time and Late) differ on the proportion of nouns in their lexicon. The Oxford CDI contains 206 nouns (defined as concrete objects), and on average children aged 18 to 25 months had 53.3% of nouns in their receptive vocabulary (STD 5.1%) and 52.3% in their expressive vocabulary (STD 12.2%). Mean proportions of nouns per vocabulary group are reported in Table 2. An ANOVA on the proportion of nouns revealed a significant effect of language group for expressive vocabulary ($F(2, 93) = 9.95$, $p < .001$, $\eta^2 = .18$), due to the Late talkers having a smaller proportion of nouns ($M = .44$) than Early talkers ($M = .58$, $p < .0001$, adjusted for multiple comparisons) and the On-time talkers ($M = .54$, $p = .001$, adjusted for multiple comparisons). No other comparison was significant and no effect was found for receptive vocabulary. This last analysis shows that Early talkers, who are more likely to produce scale errors than Late talkers, also command a larger proportion of nouns than Late talkers. *Hypothesis 2: Relationship between scale errors and knowledge of specific words*

We hypothesized that scale errors might occur more often in children who are developing a shape bias; paying more attention to shape might result in less attention to size, resulting in more scale errors. One way to test this is to determine whether scale errors appear more often when children learn names of objects whose category structure is heavily reliant on shape, to the detriment of names of objects with a size-reliant category structure. First, we determined the category structure of the early lexicon using questionnaire responses from 24 adult participants (for details refer to Supplemental material). Out of all count nouns in the OCDI (N = 184), 56.0% were found to be shape-based, versus only 23.4% size-based. Shape appears to be an important dimension in the early lexicon (as found by Gershkoff-Stowe & Smith, 2004; Samuelson & Smith, 1999), but not necessarily size. Then, we compared the rate of learning of shape-based and size-based words to the occurrence of scale errors.

A series of logistic regression analyses were conducted to predict the production of scale errors using, as predictors, the amount or the proportion of shape-based nouns produced, the amount or the proportion of size-based nouns produced, age and vocabulary groups (Early talkers, On Time or Late Talkers). Using forward regression with Wald criterion, only age and vocabulary group significantly predicted the occurrence of scale errors (mirroring the analyses presented in the sections above). The amount or proportion of shape-based nouns, and the amount or proportion of size-bases nouns produced, did not contribute significantly to any of these models.

To examine whether scale errors would be more related to the knowledge of particular words rather than shape-based nouns, we checked if the knowledge of names of the objects used in our study (chair, slide, and car), as well as adjectives depicting size, was related to the prevalence of scale errors (see supplementary material). No effect was found, indicating that the incidence of scale errors in children is unrelated to the particular object names and adjectives that children knew or produced.

Hypothesis 3: Scale errors and the first 100 nouns

We know that the shape bias seems to emerge when children have between 51 and 100 nouns in their productive vocabulary (Gershkoff-Stowe & Smith, 2004), and we just found that scale errors are more likely in early talkers. Could scale errors also be found specifically in children who have learned between 51 and 100 nouns? Gershkoff-Stowe and Smith followed up 8 children from 16 to 24 months, so we included in this analysis only the 49 children in the same age range, and who produced a maximum of 100 nouns (the OCDI contains 206 nouns). Out of these 49 children, we distinguished those who produced 50 nouns or less (N = 29; mean age: 626 days) from those who knew between 51 and 100 nouns (N = 20; mean age: 635 days). These two groups did not differ on age ($t(48) < 1$). The proportion of children who performed scale errors did not differ across the two vocabulary groups (14 children out of 29 in the low vocabulary group, and 9 children out of 20 in the higher vocabulary group, $X^2 < 1$).

Discussion

The purpose of this study was twofold: to re-examine the relation between the prevalence of body scale errors and age in children between 18 and 30 months, and to test whether the production of scale errors in young children relates to the size and properties of their lexicon.

Based on DeLoache et al.'s seminal findings (2004), we expected to find an inverted U-shape with a peak of the incidence of scale errors at 24 months. In our study, however, with a larger sample size spanning the same age range as in DeLoache et al., the peak of scale errors incidence was found in the youngest group, i.e., 18 months, and decreased with age, which contrasts with the original findings, but is in line with other studies on scale errors (e.g., Brownell, et al., 2007; Rosengren et al., 2009). While our procedure was largely similar to that of DeLoache et al., our task differed slightly in the way the experimenter encouraged children to interact with the miniature object replicas. Contrary to DeLoache et al., we did not refer to the actions while prompting the children to engage with the objects, which may have limited the number of scale errors as compared to the original study. However, this alone cannot explain the contrasting results, as the average number of scale errors per child is comparable in our study (0.82) and in DeLoache et al. (0.72). A remaining possibility is that the contrasting outcomes might be due to differences in sample characteristics - bearing in mind that results are less likely to be affected by idiosyncratic biases with increasing sample size. It is worth mentioning though that we did have comparatively more early talkers in the younger children group than in the older one – and we found, as discussed below, that early talkers are more likely to commit scale errors. This distribution might have been different in the DeLoache et al. study, with perhaps more early talkers in the middle group, explaining their high proportion of scale errors in that age range.

The absence of an inverted U-shaped function questions the existence of a developmental stage for scale errors, as is also suggested by the fact that children vary substantially in the incidence and perseveration of scale errors (Rosengren et al., 2009; Rosengren, Schein, & Gutierrez, 2010). Rather, our findings point to an explanation based on the conjunction of different developmental factors that could potentially contribute to scale errors: inhibition, object perception and representation, and motor/action coordination could conspire to produce scale errors from the onset of object manipulation skills.

The second question we asked was whether the size and the structure of children's vocabulary may be related to the number of scale errors they make. In support of our hypotheses, we found that the likelihood to produce a scale error increases with expressive vocabulary, once corrected for age. In other words, late talkers - children with smaller expressive vocabularies than their peers - are less likely to make scale errors than early talkers. Overall, the finding that scale errors are more likely to be observed in advanced talkers suggests that rapid lexical development favours inappropriate motor plans, while slower development seems to hamper them.

Why would a rapid vocabulary growth lead to inappropriate motor plans as seen in scale errors? As mentioned earlier, lexical growth is accompanied by complex changes in object perception and representation (e.g., Gershkoff-Stowe & Smith, 2004; Pereira & Smith, 2009; Yee, Jones, & Smith, 2012). With the rapid increase of the lexicon, the object shape information becomes increasingly important (e.g., Landau, Smith, & Jones, 1988): object name learning, a task that children face on a daily basis, trains the attentional system to increasingly attend to object shape and ignore other object properties, such as size. The sight of a small object may activate the representation of the general category of the objects, as they both share the same shape, overriding the object size information. In favor of this hypothesis are recent findings that children who perform scale errors in laboratory situations pay less attention to object size changes in passive looking tasks as compared to children who do not make any errors (Grzyb, Cangelosi, Cattani, & Floccia, 2017).

To examine the links between the incidence of scale errors, lexical development, and the emergence of the shape bias, our starting point was the study by Gerhskoff-Stowe and Smith (2004) who found that the early lexicon is very rich in shape-based nouns (such as cup, car, etc). Importantly, they also found that the shape bias is more likely to emerge in children who command a large number of nouns, with a dramatic increase as children produce between 51 and 100 nouns. If the emergence of this perceptual bias is accompanied by a decrease in attention towards other object features such as size, one could expect the incidence of scale errors to increase as the shape bias develops. Therefore we hypothesised that (1) scale errors would be more likely to be found as children learn more nouns; that (2) scale errors would be related to the growing knowledge of shape-based words, and concurrently, inversely related to the learning of size-based words; and that (3) a rise in scale errors would be noticeable in those children who would have learned between 51 and 100 nouns in their productive vocabulary.

We found evidence for the first hypothesis, as we reported a larger proportion of nouns in early talkers' expressive lexicon – who are more likely to produce scale errors - than late talkers. However, the two other hypotheses could not be confirmed, pointing perhaps to the limitations of this indirect correlational approach to test the relationship between scale errors and the shape bias.

An interesting finding though is that the category structure of nouns from the OCDI, which is representative of the early lexicon, reveals that size is only a defining feature for less than a quarter of all nouns, contrary to shape which characterises the majority of nouns - the latter result being similar to what was reported by Gershkoff-Stowe and Smith (2004). Another informal observation is that children's surroundings is usually replete with miniature toy versions of objects, which may contribute to reinforce the fact that size is not a reliable feature of object category, contrary to shape. Therefore, whereas the shape-related semantic information encoded in early nouns can possibly drive changes in perceptual biases, it is unlikely that the size-related information in the category structure of words can, by itself, modify children's attention (or lack of) towards size.

We are then left with two, non-exclusive, explanations as to why scale errors are more likely to be found in early talkers. The first one remains that scale errors are contingent upon the competing, growing shape bias, which has been found to emerge also once the vocabulary reaches a certain critical mass (Gershkoff-Stowe & Smith; 2004). The developing shape bias would move the attentional focus away from size information, resulting in an increase in scale errors; this explanation is correct only if one can show that the shape bias, which is stronger in early talkers than late talkers (Jones, 2003), develops concurrently with an increase in scale errors. We are currently engaged in further research linking scale errors and lexical development to shape bias more directly, through behavioural measures.

The second explanation as to why a richer conceptual and lexical system would lead to more scale errors is, more simply, based on the entropy of the perception-action system: the more complex the system, the more unpredictable it becomes, especially at a stage where all components are still maturing. The idea that increasing complexity in a system (understood as increasing interactions between its components), creates more instability, is common in physics: the second law of thermodynamics states that in a closed system, entropy never decreases spontaneously, but converges to equilibrium, which is the point of maximum entropy. The link between complexity and instability is also developed in mathematics (Briggs, 1992), in computer science (Gribble, 2001) and even second language acquisition (Larsen-Freeman, 1997); a metaphor often used is that the butterfly effect, illustrating the fact that a small change can cause a system to act in an unpredictable way. In our case, scale errors in early talkers could be seen as the incidental by-product of the greater complexity of the rapidly changing linguistic and conceptual systems, whose immature components would leave more room for mistakes.

To summarise, the key findings of this study are that body scale errors linearly decrease with age in childhood, and are more likely to be found in early talkers rather than less advanced ones. Several explanations of children's temporary failures in selecting the appropriate action for objects have been offered. Those include weak inhibitory control coupled with immaturity in integration of information processed by the action selection and the action control systems (e.g., DeLoache et al., 2004), a strong association between the object and its function that sometimes overrides size information (Casler et al., 2011), and the immature development of an accurate representation of body dimensions (Brownell et al., 2007). The results of our study point towards a complementary explanation of scale errors based on the development of the linguistic and conceptual system, in accordance with recent findings that linguistic cues influence children's scale errors (Hunley, Hahn, 2016; Oláh et al., 2016). More research will be needed to fully understand the role of language acquisition in perceptual-motor development, beyond the fascinating example of scale errors.

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Tables

Table 1

Characteristics of scale errors performers: frequency of scale errors (F), number of children (N), number of scale errors (and percentage) per object, age in days, number of male and females (and percentage), CDI score (out of 416 words) in the receptive and expressive modality. Standard deviations are in brackets.

F	N	Scale Errors			age	gender		CDI	
		chair	slide	car		male	female	receptive	expressive
1	22	8 (36.4%)	12 (54.5%)	2 (9.1%)	671.4 (77.0)	11 (50%)	11 (50%)	278.6 (90.2)	161.7 (107.0)
2	9	8 (44.4%)	8 (44.4%)	2 (11.2%)	642.7 (63.8)	7 (77.8%)	2 (22.2%)	257.8 (109.6)	149.8 (138.3)
3	8	7 (29.2%)	11 (45.8%)	6 (25%)	715.0 (93.9)	6 (75%)	2 (25%)	302.9 (105.0)	234.1 (145.3)
4	7	7 (25%)	15 (53.6%)	6 (21.4%)	704.4 (94.9)	3 (42.9%)	4 (57.1%)	267.0 (117.3)	170.4 (122.0)
5	1	0 (0%)	4 (80%)	1 (20%)	599.0	1	-	364.0	129.0
7	1	1 (14.2%)	3 (42.9%)	3 (42.9%)	822.0	-	1	382.0	330.0

Table 2

Characteristics of each vocabulary group (Early, On-time and Late), in the receptive and expressive modality: number of children (N), age in days, CDI score (out of 416 words), proportion of nouns in their CDI score (% nouns) and proportion of children who perform at least one scale error (% SE). Standard deviations are in brackets.

	Receptive					Expressive				
	N	age	CDI	% nouns	% SE	N	age	CDI	% nouns	% SE
Early	29	637.6 (59.4)	330.6 (68.6)	0.52 (.04)	0.62	23	639.0 (53.2)	217.8 (99.3)	0.58 (.06)	0.70
On-time	35	686.8 (69.8)	291.9 (99.8)	0.54 (.04)	0.40	48	687.2 (71.7)	181.6 (121.3)	0.54 (.11)	0.42
Late	32	705.8 (64.2)	197.9 (86.5)	0.54 (.06)	0.34	25	697.1 (69.2)	59.6 (42.2)	0.44 (.15)	0.28

Figure captions

Figure 1. The child-size toys and their miniature replicas.

Figure 2. Mean number of scale errors per age group (*N* = 125): Group 1 (18 to 20 months, *N* = 21), Group 2 (20.5 to 24 months, *N* = 51), Group 3 (24.5 – 30 months, *N* = 53). Standard errors are reported.

Figure 3. Proportion of scale error performers per age group (*N* = 125): Group 1 (18 to 20 months, *N* = 21), Group 2 (20.5 to 24.0, *N* = 51), Group 3 (24.5 to 30, *N* = 53).

Figure 1

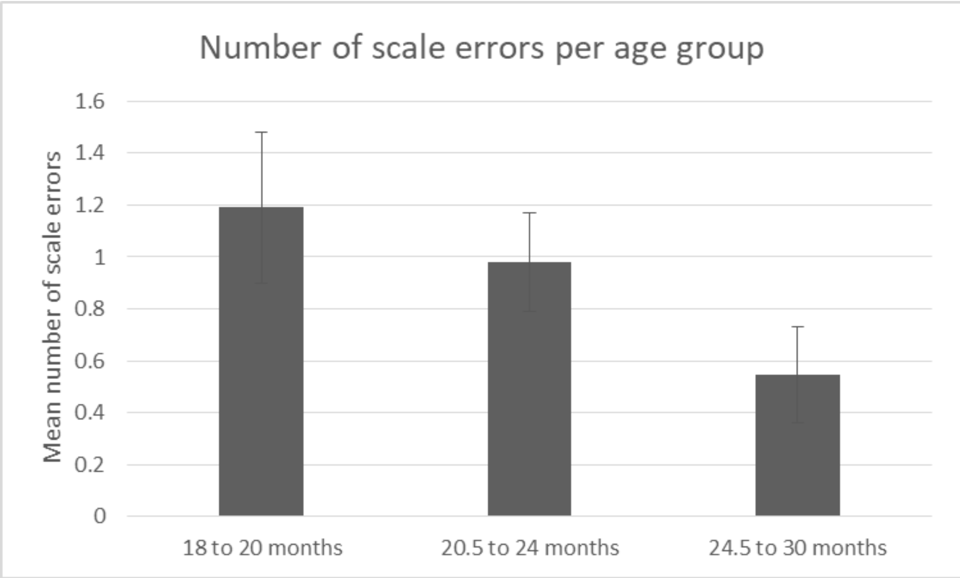
Number of scale errors per age group
Mean number of scale errors
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
18 to 20 months
20.5 to 24 months
24.5 to 30 months

Figure 2

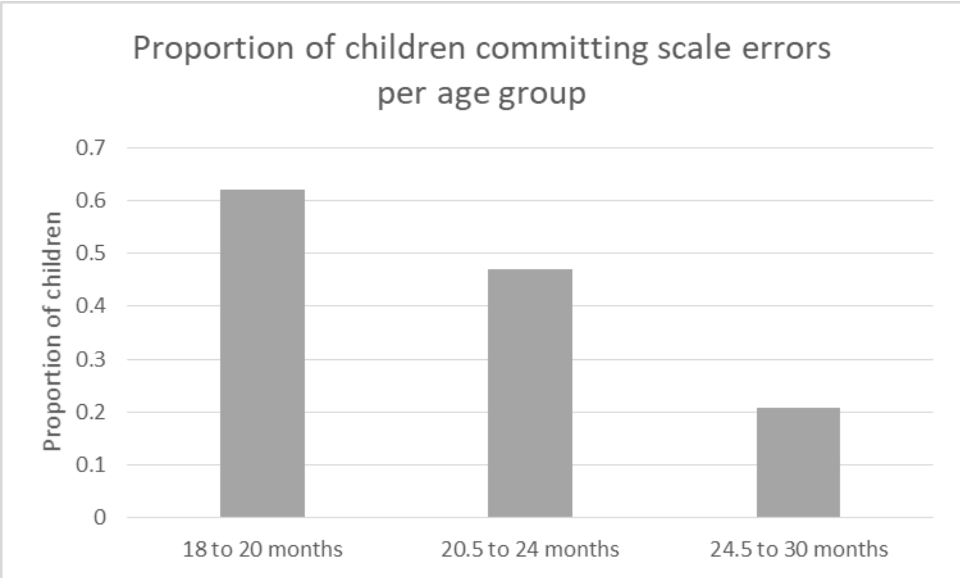
Proportion of children committing scale errors per age group
Proportion of children
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
18 to 20 months
20.5 to 24 months
24.5 to 30 months

Figure 3