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Abstract

Theory of Mind (ToM) refers to the ability to attribute beliefs to oneself and others. The present study used a dynamic systems approach to assess how environment may affect the development of second-order ToM (e.g., John knows that Mary knows that he went out yesterday). ToM is divided into two major dimensions: comprehension (i.e., to understand a mental state) and prediction (i.e., to predict someone else's future behaviour or mental state). Two age groups were assessed: 5-6 and 10-11 years old children. In both age groups, participants were assigned to a condition of "Support" (help provided) or "Non-Support" (help not provided).

Results show that second-order ToM follows a dynamic growth law that depends on support. Support facilitates performance in ToM production (i.e., to predict one's future behaviour) for both the 5-6 and 10-11 year old children. Interestingly, the 5-6 year olds who received support presented an increase in the second-order prediction performance at the expense of the second-order comprehension, suggesting that a temporary dip in comprehension performance may facilitate the development of mental rules to predict one's future behaviour.

Keywords

Development of Second Order Theory of Mind; Dynamic Systems; Environmental Influences; Comprehension of Mental States; Prediction of Mental States.

Theory of Mind (ToM) comprises both cognitive and emotional aspects necessary for the understanding of someone's thoughts and behaviour. More cognate aspects, however, allow the binding of relevant information to render an event (e.g., somebody's behaviour) comprehensible (Frith, 1989), which notably involves the use of executive functions (EFs; see Müller, Liebermann-Finestone, Carpendale, Hammond, & Bibok, 2012).This allows the attribution of mental states (e.g., beliefs, intentions, emotions) to oneself and others, but also involves the use of these mental states to predict and explain one self's behaviour as well as others' (see Imuta, 2016; Mitchell, 1997).The ability to mentalise is not a unique human ability (Premack & Woodruff, 1978), and even primates such as orangutans and chimpanzees are able to distinguish intentional behaviour from accidental actions(see for instance Call & Tomasello, 2008; see also Tomasello, Call, & Hare, 2003).

In humans, ToM normally develops following a certain path (see Wellman, 1990; Wellman, Cross, & Watson, 2001; Liu, Wellman, Tardif, & Sabbagh, 2008): from an implicit and basic theory of others' desires and intentions to a more explicit belief theory, where a progression of new conceptual insights generalise and modify its structure and functioning. For instance, the ability to understand true beliefs is followed by the understanding of false beliefs, or an understanding of first-order beliefs leads to an understanding of second-order beliefs and so on (see also Wellman & Liu, 2004).

Although understanding false beliefs is considered to be a strong indicator of ToM development, research has shown that even infants possess a rudimentary ability to understand the mind of others (see for instance Slaughter, 2015). Moreover, older children can understand both lies and deception, which enables more complexity in strategy in late adolescence and early adulthood (Dumontheil, Apperly, & Blakemore, 2010; Peterson & Siegal, 2002; Vetter, Leipold, Kliegel, Phillips, & Altgassen, 2013; Valle et al., 2015). However, a clear change in the understanding of false beliefs can be observed in 3 to 6 year olds who are typically developing and become able to distinguish between someone's beliefs and their own, and to understand the intention and belief of a person (Astington & Gopnik, 1991; Astington, Harris, & Olson, 1988; Gattis, Bekkering, & Wohlschrager, 2002; Saxe, Carey, & Kanwisher, 2004; Gopnik & Wellman, 1994; Mitchell & Riggs, 2000; Onishi & Baillargeon, 2005; Wellman, 1991).

This change in ToM development is supported by dynamic systems and physiological studies revealing that changes around 6 years of age coincide with a move from simpler thought processes towards more coordinated ones (Case, 1991; Fischer & Bidell, 2006). One possibility is that in young children ToM is mainly based on an innate biological form of empathy which progresses into a more cognate form of ToM understanding from the age of 3-4 (Low, 2015; Preston & de Waal, 2002).

More complex forms of ToM emerging at this age can be observed in the dynamic system literature associated to regressions, that is, when an ability (or component of) is temporarily impaired concomitantly with the emergence or refinement of another (see Blijd-Hoogewys, 2008; Blijd-Hoogewy, Van Geert, Serra, & Minderaa, 2008). This supports the idea that for an ability to develop, others may temporarily suffer from it in order for this ability to make its way in the cognitive skillset of an individual.

Furthermore, changes in ToM complexity at this age might not be the result of ToM development *per se*, and other cognitive components may play a role. Another possibility is that since the switch from an implicit to a more explicit form of ToM may involve conscious thought and action, then executive functions might play a role (Carpendale & Lewis, 2006). This implies the use of EFs in synergy with language and working memory (see Apperly, Samson, & Humphreys, 2009; German & Hehman, 2006; Mutter, Alcorn, & Welsh, 2006). Thus, the concomitant development of EFs and language abilities may facilitate the switch from an implicit to an explicit ToM (San Juan & Astington, 2012), though this can be hindered in the presence of an implicit ToM deficit as found in children with autism spectrum disorder (Schuwerk, 2015).

This is particularly important for higher levels of ToM recursivity (i.e., second- and third-order nested belief), where an increasingly more complex meta-representational workload is necessary: 'I think that you think that s/he thinks [second order] that another person thinks [third order]'. A typical adult is able to follow only a few levels of recursions, and often loses track at the 2nd or 3rd level (Verbrugge & Mol, 2008; see also Valle, Massaro, Castelli, & Marchetti, 2015; Miller, 2012; and the pioneering study of Perner & Wimmer, 1985).

Our study examined short-term dynamic processes that might lead to long-term changes in the ability of children to master ToM. We assessed the effect of interacting with an expert adult on children's ToM strategies for the understanding of someone's beliefs, emotions or intentions (i.e., 'ToM comprehension'), and the ability to actively make a prediction of one's future behaviour or mental state (see Figure 1). This distinction is similar to what has been proposed as implicit and explicit ToM respectively (see Low & Perner, 2012).

Since conflict inhibition is measured by EFs tasks then the emergence of false belief understanding may be the precursor of the children's ability to predict a conflict between their own and somebody else's perspective, such as the scenarios faced by children whilst they are playing PC games (i.e., Strategic Game, see Methods). The acquisition of false belief understanding correlated with substantial changes in EFs around the age of 6, involving inhibition of a dominant response

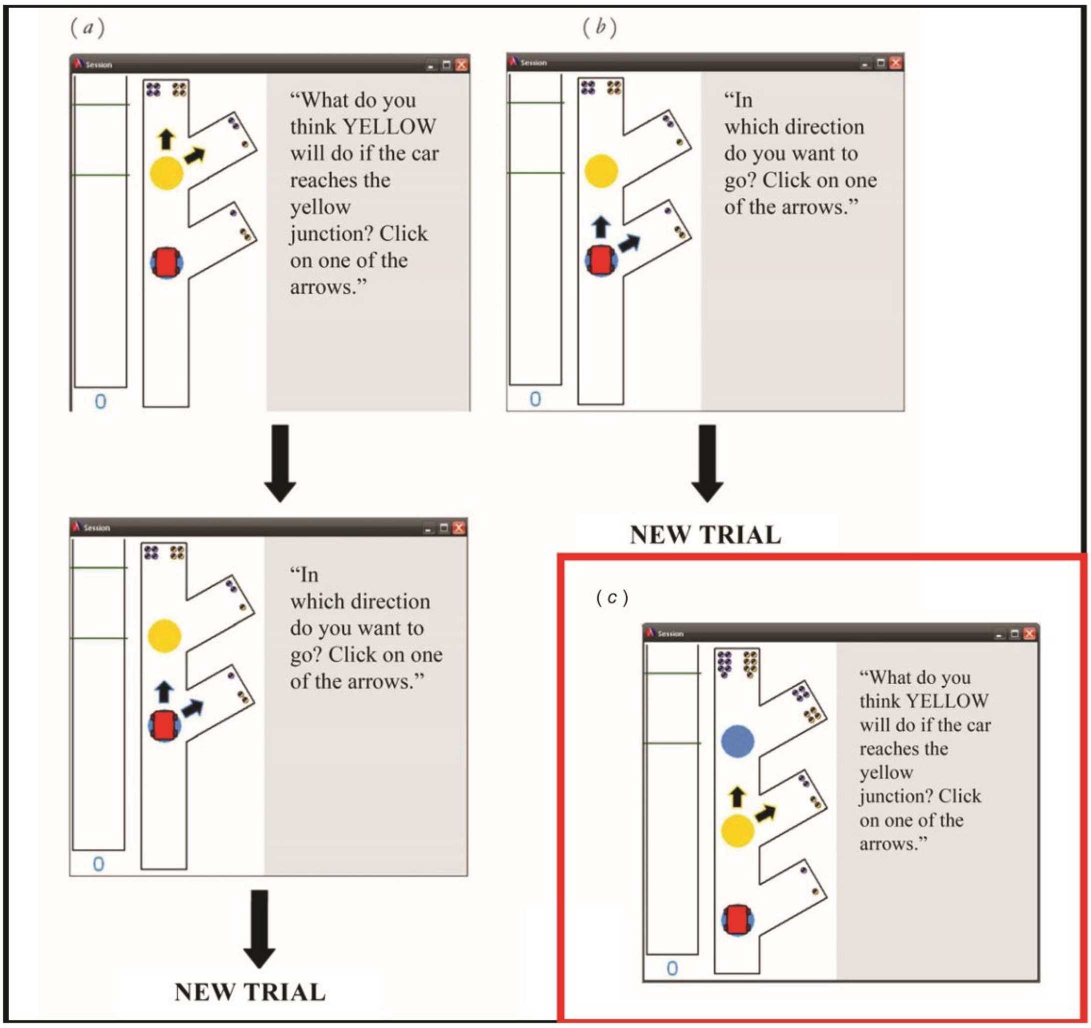

Figure 1. First- and second-order strategic game. In (*a*) top and bottom, the sequence of events in the support condition, whereas (*b*) illustrates the game in the condition without support (i.e., absence of explicit request for the prediction of the opponent's behaviour). (*c*) Displays the second-order Strategic Game. Participants are required to think which direction the PC opponent will go at the second junction.

and the subsequent initiation of a subdominant response, which reflects the scenario present in the Strategic Game (see for instance the discussion in Müller, Liebermann-Finestone, Carpendale, Hammond, & Bibok, 2012).

Dynamic Systems have been used in different domains to study how elements/individuals influence each other on a given timescale, leading to self-organisation processes (Thelen & Smith, 1996; Witherington, 2015). One way to address these dynamics is to use coupled equation approaches to model one-to-one dyadic interaction such as parent-child or teacher-child relationships through childhood, but also during adolescence and early adulthood (several implementations can be found in Van Geert, 1994; Steenbeek & van Geert, 2007; Steenbeek & van Geert, 2008; Hamaker et al., 2009; Steele & Ferrer, 2011; Butner *et al*., 2007).

In this study the theoretical framework of one of these dyadic interaction models (Steenbeek & van Geert, 2007; Steenbeek & van Geert, 2008) was used to interpret interactions between the ability to understand and predict mental states. The application of dynamic systems to the development of ToM is not common and formal modelling of social interaction which plays a crucial role in ToM development is scarce (Hughes, 2011; Hughes & Leekam, 2004; Pavarini, de Holland Souza, &Hawk, 2013; Hayashi, 2007).

These systems are driven by two different types of parameters: *order parameters*, macroscopic/dominant variables that reflect dominant modes of the interactive system as a whole. These parameters emerge from the interaction/coordination of a second type of microscopic parameters, called *control* parameters: they represent all forms of coordination that the elements of the system can allow (for a discussion see Thelen & Smith, 1996; Steenbeek & van Geert, 2008).

In our framework, ToM development can be conceived as the result of an interaction between two order parameters (ToM comprehension and prediction of mental states) and three control parameters (i.e., environment, growth rate and carrying capacity). In dyadic systems, the interplay between these two sets of parameters appears to occur through a causal circular process both in the short- and long-term (i.e., respectively comprehension and prediction), where aspects of daily comprehension of mental state and behaviour have a long-term effect on the ability to predict someone's behaviour/mental state. Figure 2 gives an outline of the order and control parameters on both short- and long-term time scale in our model of interaction framework.

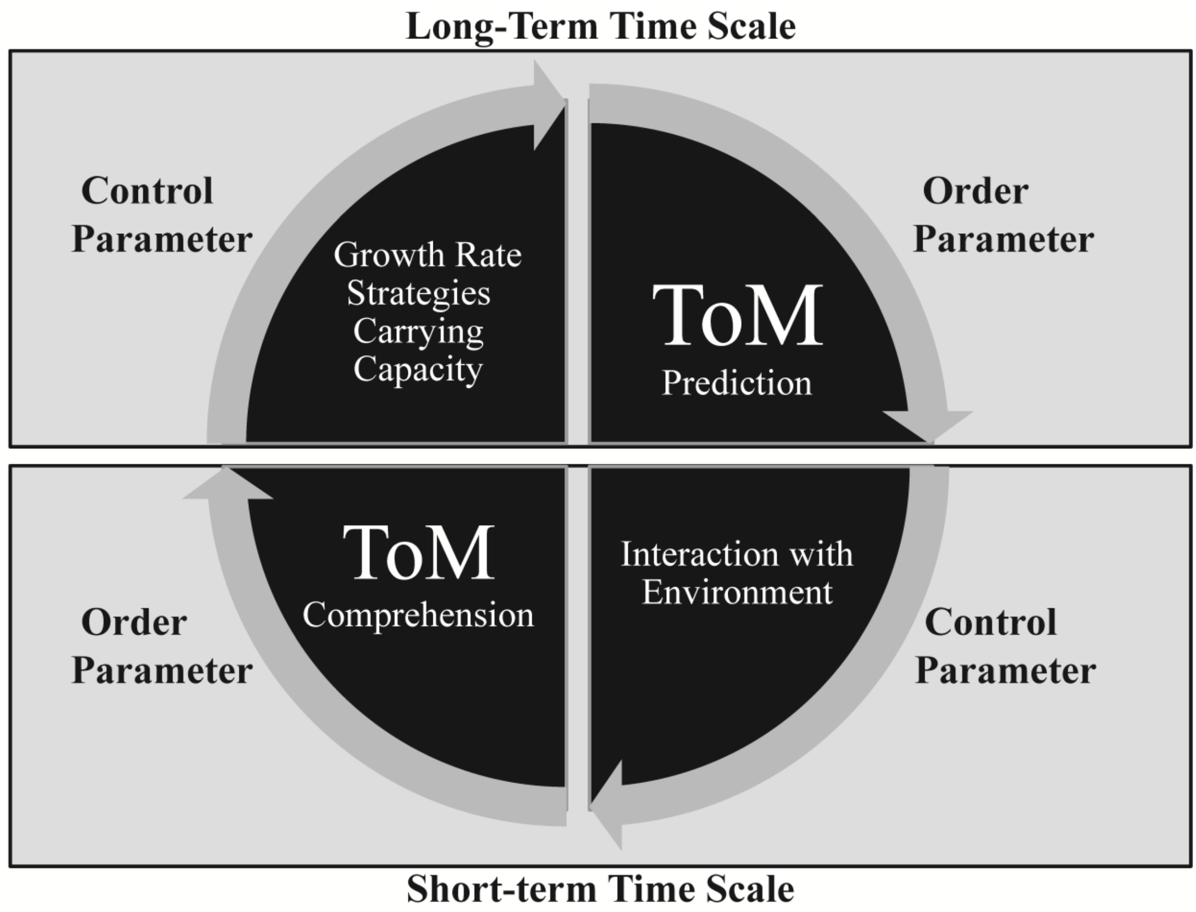

Figure 2. The framework used to present the interaction between the coupled variables "ToM Comprehension" and "ToM Prediction". Interaction with the environment supplies a valuable help to enable a subject to comprehend a certain level of mental representation. This information, in turn, can be used in social strategies to facilitate subjects in predicting other's mental states or behaviour. The effect these strategies have on agents in social contexts leads to changes in the social environment to which subjects are exposed.

Long-term changes in ToM prediction influence the interaction with the environment, a control parameter situated on a short-term time scale; interaction with peers and expert figures determine changes in the ToM comprehension level of a child in the short-term, and this in turn influences the ability to predict mental states (ToM prediction), an order parameter that changes on a long-term scale. This order parameter is controlled by control parameters such as the environment, the speed at which the performance grows, and a performance limit depending on the subject's personal capability (i.e., carrying capacity). In other words, in the long-term subjects' comprehension of mental states affects their prediction rules to predict future mental states and behaviours. Since ToM has a recursive nature (i.e., mental states can be nested at several levels of recursivity), this framework has the potential to explain the interplay between comprehension and prediction at any ToM order, as well as transitions from one level to another (i.e., first- to second-order ToM).

Although the relationship between support and development of second-order ToM has already been the focus of research (see for instance, Hayashi, 2007), dynamic system research in developmental psychology has not yet addressed the dynamics between different modes of ToM use (i.e., comprehension/prediction) and the effects of the environment. In order to study environmental influences on comprehension and prediction of second-order mental states, two conditions were designed. Since more complex phenomena (e.g., ToM second-order predictions) can be observed compared to an environment where support is minimal (see for instance, Fischer & Bidell, 2006), a *functional level* (i.e., condition with support) can be observed in given skill domain (e.g. ToM) when a child is given low support and allowed to work on his/her own. This allows us to observe the highest skill level that a child can achieve by his/herself. Conversely, an *optimal level* (i.e., condition with support) is achieved when high support is provided. These two conditions allow to measure the two upper limits of the child's performance, that is the best performance obtainable without support and the best achievable with support.

Two age groups were assessed: 5-6 and 10-11 year olds. We predicted that although both age groups may be already capable of taking a second-order perspective (i.e., second-order comprehension acquired), 5-6 year old children may be poor to predict someone's future behaviour in a task where second-order ToM prediction is required. Conversely, for the 10-11 year olds, we would expect minimal second-order ToM differences between the two environmental conditions, since this group of participants is assumed as control group, and should present small differences irrespective of the environmental conditions. Crucially, the help supplied in the condition with support should influence the comprehension-prediction dynamic relation in a way that improves second-order ToM prediction rules to predict another person's behaviour, with larger differences for the 5-6 year olds than the 10-11 year olds.

Methods

Stimuli and Procedure

A set of tests assessed the ability to mentalise first- and second-order ToM comprehension and prediction. False-belief stories were used to assess the ability of a child to understand that a character's action might be based on a wrong belief. Thus, a child will present a correct belief whereas the character has a false belief. Stories were read while at the same time drawings were shown to illustrate the various elements of the story. Children experience this type of assessment as a 'being read to' activity, rather than a 'being tested' activity (Blijd-Hoogewys & van Geert, 2017). To assess prediction of mental states, two PC games (Strategic Games) were developed. These were sequential games that are particularly suitable for use with children because of the attractiveness of its audiovisual components.

First- and second-level of recursion were measured for both comprehension and prediction (e.g., "John knows that Mary [first order] knows that [second order] he did not go to school yesterday") by using parallel forms of false belief stories (Flobbe, 2006; Flobbe, Verbrugge, Hendriks, & Krämer, 2008; Blijd-Hoogewys, 2008), and computer games(Flobbe, 2006; Flobbe *et al.*, 2008; further details are provided in the Supplemental Methods).

Design

A mini version of a cross-sectional microgenetic study was adopted. Models have already been validated with only three repeated observations (see for example: Van Geert & Steenbeek, 2005ab; Vleioras, Van Geert, & Bosma, 2008). A mixed design was implemented with one within-subjects factor (session: three weekly testing sessions) and two between-subjects factors (age groups: 5-6, 10-11 year olds; and environmental condition: support, non-support). Environmental effects for the prediction tests were assessed using t-tests with theoretical distribution correction (see supplemental Methods), whereas for the dynamic system fitting a dynamic *hyperlogistic model* used in a wide variety of fields (see Banks, 1994; Van Geert, 1991;Fischer & Bidell, 2006) was implemented. The model provides restricted and exponential growth equations as a function of time to explain ToM development (Figure 3), that is special cases that can be derived from its general formula to fit different growth patterns:

$$\frac{\Delta L_t}{\Delta t} = r \cdot L_t^p \cdot (1 - d \cdot L_t^s)^q \qquad \text{Equation 1}$$

Figure 3. Graphical illustration of restricted and exponential restricted growths. In an ideal scenario, Growth (*y*-axis) shows a quick or slow increases as a function of time (*x*-axis). Note: the temporal scale represented in the figure is arbitrary: it can indicate the number of hours or the number of days, months or years as well. The same applies for the growth. Analogously, growth can be assessed by the performance to a psychometric test, in terms of accuracy, reaction times, etc.

Goodness-of-fit for the dynamic models derived from Equation 1 were assessed using a G^2 test statistic.

The study comprised three weekly sessions and tests were administered in the following order: 1st and 2nd order comprehension test, 1st and 2nd order prediction test. The entire session took 50 minutes and was terminated if the participant exceeded this limit (a zero score was given to the missing item).Since the format of our set of tests was different (i.e., stories and games) two distinctive modes of support were implemented. For false belief stories support was provided by repeating crucial details - what has happened and what has not been understood by the child over the stream of events. During prediction tests, support was supplied by providing a further explanation of the strategies used by the opponent when the subject was unable to predict the opponent's intentions. Conversely, when support was not supplied, subjects were expected to master first- and second-order mental states: support was not provided and children were assumed to be able to understand false beliefs and to actively produce a prediction of the opponent's behaviour on their own. (Further details for the assessment of the environmental effects and the dynamic system implementation are provided in the Supplemental Methods).

Participants

Two groups of subjects completed the study: 5-6 year old children from a primary school ($n_1 = 12$) and 10-11 year old children from a middle high school ($n_2 = 12$). Each age group was divided in two subgroups and children were randomly assigned to either the support or unsupported condition.

The schools were two well-established public schools (Tuscany, Italy) who welcomed the project and helped to recruit families for the project. Parents signed a written informed consent and all sessions were audio-recorded; consent for the audio-recording was obtained separately. The educational background of the parents was mixed. First-order ToM was used as exclusion criterion and pupils were screened for their ability to use first-order ToM; however, none of the recruited subjects met this exclusion (see Supplemental Methods for further details on screening).

The mean age of the 5-6 age group was 6.26 year (median = 6.25; range 5 years and 11 months to 6 years and 9 months) and the mean age of the 10-11 age group was 11.24 year (median = 11.25; range = 10 years and 10 months to 12 years and 4 months). An equal number of females and males was allocated in each age group and subgroups (i.e., conditions with and without support).

Result

In order to assess the main effect of support for ToM comprehension and prediction t-tests were carried out irrespective of the ToM order (i.e., first- and second-order), and of the weekly session.

The proportion of correct answers (p) wasobtained for each subject and converted to its corresponding t-value. These t-values were first used to check for guesswork: both sub-groups (i.e., condition with and without support) and age groups answered significantly away from the theoretical distribution (all p-values $< .001$). Next, independent t-test compared the condition with support (supported condition) and without support (unsupported condition). In order to account for the different variance between the groups, Welch's correction was used.

The 5-6 year olds in the supported group were 12% more accurate in the comprehension tests compared to the unsupported group (participants in the supported condition may improve their accuracy up to 24%; the mean proportion difference was

$.94 - .82 = .12 \times 100 = 12\%$; t(26.51) = 2.25, $p<.05$, CI_{95}= .01, .24). Support appears to help subjects improve their ToM skills. The 10-11 age sub-group who received support was 4% more accurate than the unsupported counter-group (i.e., $1 - .96 = .4 \times 100 = 4\%$), but this result was non-significant (t(17) = 1.37, p =.18, CI_{95} = -.01, .08; means: SC = 1,UC = .96; H_0: true diff. in means = 0). This is because the second-order ToM comprehension is strongly consolidated in the 10-11 years olds.

Differences between the condition with and without support were also analysed for the ToM prediction tests. The 5-6 year olds benefited when support was received. Those who were assigned to the condition with support scored 28% better than those who did not receive support (i.e., $[.73 - .70] - [.50 - .25] = .28 \times 100 = 28\%$). An independent t-test, showed that with 95% confidence level participants who received support perform up to 13% better than those in the unsupported condition (t(28.68) = 5.67, $p< .001$, CI_{95} = -.07, .13; means SC = .73, UC = .70; H_0: true diff. in means = -.25). Figure 4 depicts statistical and empirical distributions for the prediction tests.

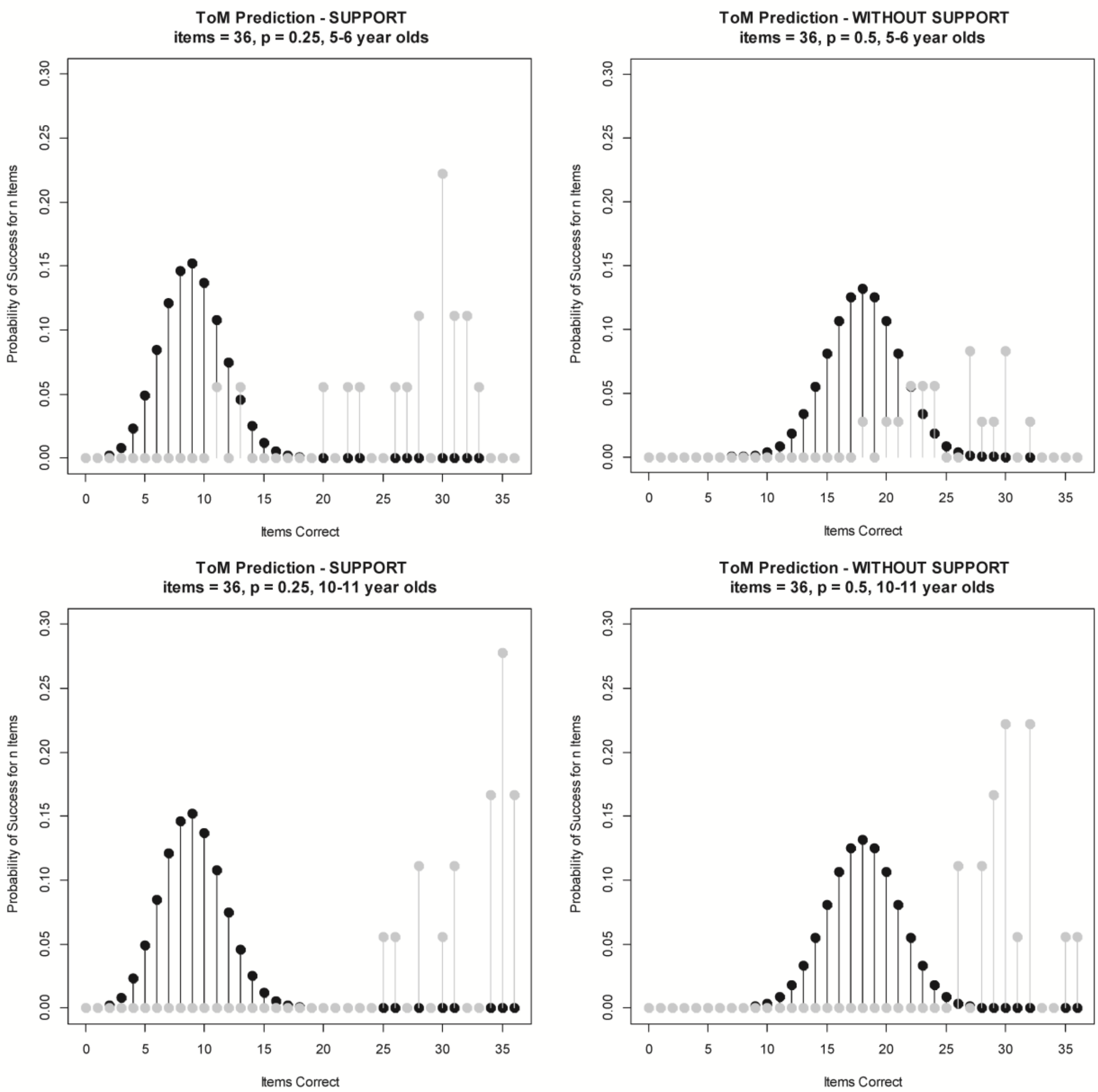

Figure 4. The theoretical (in black) and empirical probability distribution (e.g. proportion of mean accuracy; in grey for support and no support) for the ToM prediction tests (i.e., number of trial items per game: 36). On the left: distributions for the condition with support are shown. On the right: distributions for the condition without support. Top panel shows the 5-6 year olds whereas bottom panel the 10-11 year old group.

Note: the analysis comprises collated data irrespective of the ToM order and of the weekly sessions (i.e., 1, 2, 3), *n* = 18 per environmental condition (i.e., support/no-support), and *n* = 36 per age group (5-6/10-11 year olds).

A similar trend was found for the 10-11 year olds who received support, who scored 31% higher than in the unsupported condition (i.e., $[0.90 - .084] - [0.50 - 0.25] = 0.31 \times 100 = 31\%$). An independent t-test confirmed that in statistical terms up to 12% of those children who received support performed better than the unsupported ones (t (31.11)= 10.52, $p < .001$, CI_{95} = .00, .12; means SC = .90, UC= .84, H_0: true diff. in means = -.25).

Overall, these results show that both age groups performed better in the condition with support, although the support received by the experimenter during the prediction tests appears to have a stronger impact on second-order prediction than comprehension. ToM at 10-11 years of age is robust and allows subjects to complete the tasks, even without support; whereas, for the 5-6 years old children the second-order ToM is more transient: it shows an enhanced level when support is given but this increase is not observed in the unsupported condition.

The dynamic fitting showed that both the restricted and the exponential models provide a good fit for the empirical data in both the conditions with and without support respectively (all p-values $>$ .97; see Figure 5). Table 1 reports the estimates for the growth parameter. Second-order ToM growth shows an accelerated trend in the first sessions in the condition with support at 5-6 years of age. We noticed an acceleration of the growth, (i.e. performance), in the supported compared to the unsupported condition for both age groups. However, it appears that the 5-6 year olds receive greater benefit from the support than the 10-11 year olds.Minor differences –that decreased even further across the weekly sessions– were observed in the 10-11 age group.

As to the differences between second-order comprehension and prediction, second-order ToM comprehension diminished after initially having accelerated its growth it, and generally growth was faster in the 5-6 year olds group who received support.In the condition without support for the same age groupal growth was slower and overall reached a lower level. Second-order ToM prediction was higher and faster in the 5-6 year olds who received support (see Figure 5 top), whilst performance remained more around chance level (p=.5) and somewhat slower in the same age group who did not receive support.

In the 10-11 years of age group, second-order ToM is robust and allows subjects to complete the tasks irrespective of the second-order ToM dimensions and whether or not they receive support; whereas, for the 5-6 years old children the second-order ToM is more transient: it shows an enhanced level when support is given but this increase is not observed in the condition without support.

Interestingly, concomitantly with a decrease in second-order comprehension, an increase of second-order prediction in the supported condition for the 5-6 age group (see Figure 6) was observed, which may suggest a temporary regression. This pattern neither is present in the unsupported condition for the 5-6 year olds nor in the supported and unsupported conditions for the 10-11 age group. This offers support to the idea that the 5-6 year olds in the condition with support benefit from the help supplied, although at the expense of a temporary decrease in second-order comprehension performance.

In the condition with support, dynamic systems indicators such an increase in variability from session two to session three (from 0% to 8% for the 2nd order comprehension; see Figure 5 top-left graph) together with a decrease in growth (i.e., a negative r' parameter) may be indicative of an increase in cognitive resources consumption (hence the second-order comprehension dip), and may be used to demonstrate transitions in which an increase in the performance of one (developing) component, i.e., second-order prediction, occurs at the expense of another component, i.e., comprehension.

Furthermore, individual performance dynamic fitting was also carried out, showing similar results; however, not all the subjects presented a pattern that resembles the one obtained by averaging across subjects (i.e., not everyone showed a regression in the ability to understand mental states), though dynamic fitting on single individuals showed that learning to use second-order ToM follows dynamic rules for both comprehension and prediction of mental states (see Supplemental Results).

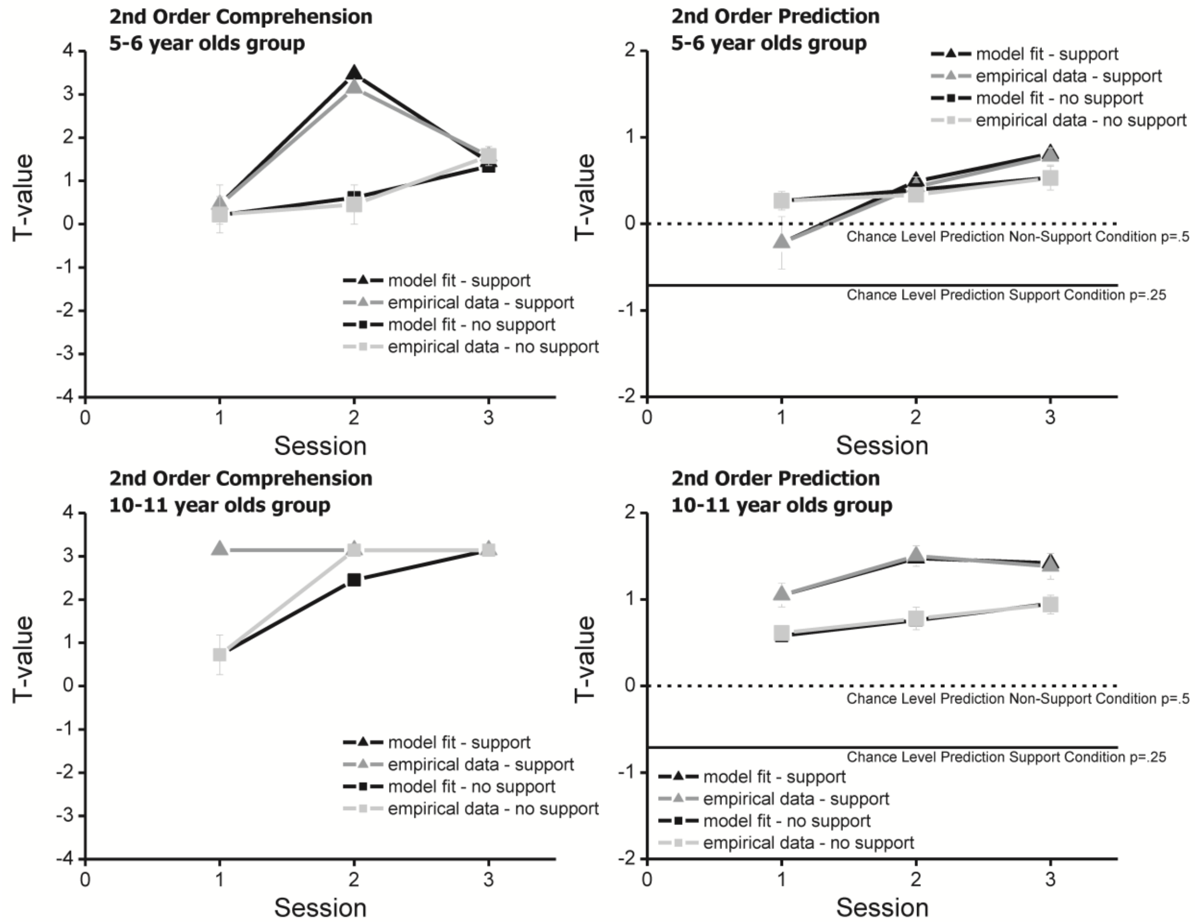

Figure 5. Accuracy proportions for empirical and predicted values ranging between 0 and 1 were transformed into *t*-values prior to plotting. Graphs depict the model fits and the empirical data through the three week sessions. The 5-6 year olds children are depicted at the top, while the 10-11 year olds at the bottom.
Note: some conditions present an overlapped offset, hence they are partially visible; environmental conditions (i.e., support/non-support), n = 6 per condition, age group (i.e., 5-6/10-11 year olds), n = 12 per group.

Table 1. Summary of the parameter estimations for the two dynamic models fitted based on the average performance of the groups. Results shows that both second-order ToM components are fitted well by the restricted model and the exponential restricted model in the conditions with and without support respectively.

With Support - Restricted Model		
5-6 year olds group	Growth Rate	CI_{95} [LL, UL]
Second Order Comprehension	-6.51	[-14.94, 1.92]
Second Order Prediction	0.37	[0.29, 0.45]
10-11 year olds group		
Second Order Comprehension	0	[0, 0]
Second Order Prediction	0.17	[-0.11, 0.46]
Without Support - Exponential Model		
5-6 year olds group	Growth Rate	CI95 [LL, UL]
Second Order Comprehension	0.23	[0.23, 0.23]
Second Order Prediction	0.07	[0.07, 0.07]
10-11 year olds group		
Second Order Comprehension	1.11	[-0.19, 2.41]
Second Order Prediction	0.07	[0.06, 0.09]

Note: CI_{95}, confidence interval at 95%, LL, Lower Limit, UL, Upper Limit; environmental conditions (i.e., support/non-support), n = 6 per condition, age group (i.e., 5-6/10-11 year olds), n = 12 per group.

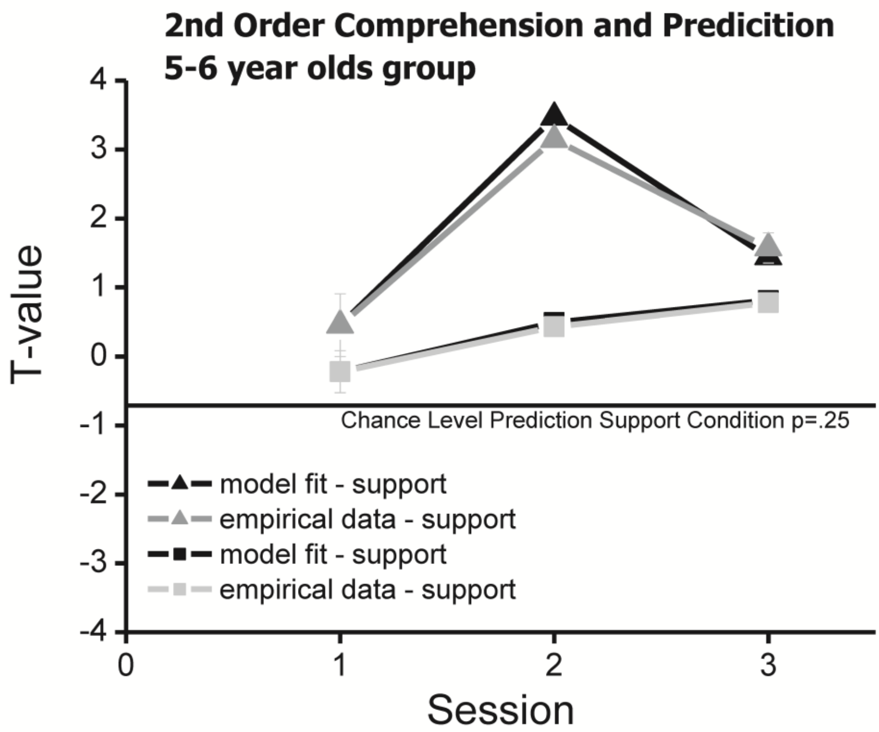

Figure 6. Cross-comparison between second-order ToM comprehension and prediction for the condition with support in the 5-6 year old group. Data show a decrease in performance for the second-order comprehension concurrent with an increase for the second-order prediction performance.
Note: environmental condition (i.e., support – one condition), *n* = 6 per weekly session (i.e., 1,2,3), age group (i.e., 1 group in the comparison shown in the artwork – 5-6 year olds), *n* = 6.

Discussion

Our study used dynamic systems to examine second-order ToM development. Results show that a hyperlogistic model fits the empirical data for second-order ToM comprehension and prediction, suggesting that second-order ToM growth follows a dynamic growth rule. Furthermore, support appears to have a substantial effect for the 5-6 year olds when they have to predict their opponent's behavior (i.e., prediction tests), compared to their peers who did not receive it.

In contrast to the Wellman, Cross and Watson's meta‐ analysis (2001, i.e., having to predict an action that follows from a belief is no more difficult than identifying the belief itself) our study showed that comprehension might be the precursor through which children develop the ability to predict future behaviours or mental states. Thus, a circular mechanism may account for our results (see Figure 2). Our goal was to empirically demonstrate that a dynamic system framework already used in other developmental contexts (see for instance Steenbeek & Van Geert, 2008) can be used to explain the dynamics involved in ToM development. Although Steenbeek and Van Geert's model is not mathematically implemented in the present study (i.e., we used two dynamic models derived from a hyperlogistic dynamic law to fit the two variables separately), it allows us to explain the dynamics involved in a social context where ToM is utilised. As for Figure 2, the environmental condition 'with support' (i.e., the experimenter, one of the agents) provides fundamental ToM comprehension strategies to a 5-6 years old child (the second agent in the dyad); this in turn has a facilitatory effect for the planning of strategies to be actively used to predict one's thoughts or behaviour. Later on these strategies have a retroactive effect (i.e. *ex post facto*) on the environmental interaction (i.e., agents adapts to the child's ToM level); this is implicitly 'tuned' to the current child's ToM level, (e.g. a more complex level of ToM prediction and/or comprehension).

Support provides the necessary scaffoldings for developing a cognitive component that allows for a quicker and better prediction of second-order mental states. However, it is debated whether this might be strictly ToM-based or the result of EFs developing at around the age of 6. A number of accounts have been proposed to explain the relationship between ToM development and EFs, amongst which proposal discuss that ToM may be the precursor for EFs or vice versa (Moses & Tahiroglu, 2010; Perner & Lang, 1999; Moses & Carlson, 2004; Sabbagh *et al*., 2006), as well as suggesting that ToM makes the use of EFs components (Carlson, Moses, & Hix, 1998), particularly when this is necessary for the prediction of mental states. Support plays a crucial role in learning to use second-order ToM prediction, and could be used as a control parameter, along with others reflecting Piagetian processes within the individual (i.e., assimilation and accommodation) and contextual parameters in a Vygotskian perspective (i.e., actual development and zone of proximal development). A future implementation based on the Steenbeek's and Van Geert's (2008; see also Van Geert, 1998, 2000) may be used to predict and describe potential performance outcomes under different environmental/contextual conditions and ToM components (i.e., level of recursion, dimension: comprehension/prediction).

One limitation of our study was not to use third order tests to assess if the support supplied could be benefited from the 10-11 years olds; this would have allowed a comparison with the 5-6 years olds had this been observed in the older age group. For instance, further regressions may have been observed in the older age group if more complex tests were used (see for instance Perner & Wimmer, 1985). However, this does not affect the relevance of our findings that show a clear change in the ability to use second-order ToM prediction more efficiently when 5-6 year old children are confronted with an unfamiliar task such as the ability to explicitly predict future mental states.

Development of second-order prediction appears to make use of a more explicit form of ToM, since an individual must be actively engaged in the estimation of a future mental state, rather than understanding a mental state, which may presume a more passive process (i.e., comprehension). It is therefore not surprising that at the age of 6 EFs undergo a remarkable stage of maturation and that this may have important implications for the development of ToM (Brocki & Bohlin, 2004; Carlson, Moses, & Breton, 2002). For instance, some authors have suggested that EFs may also be a prerequisite for the acquisition of explicit ToM (Moses, 2001; see also Devine & Hughes, 2014).

Furthermore, differences found in our results between the ability to understand past mental states (as reported in a story) or to predict future mental states (as emerging through PC games), may suggest that at this age the dip found in the false belief understanding might be explained as a result of the emergence of the ability to use ToM more explicitly. For instance, this may include the ability to use ToM through time, whereby ToM can be used forwards (i.e., to predict), but also backwards (i.e., to comprehend a mental state). This higher mastery of ToM may also contribute to the temporary conflict between competence and performance (Marcus, 2004): the development of second-order prediction of mental states interferes with second-order comprehension.

Since both comprehension and prediction were fitted separately with a dynamic function that comprises a growth factor (r') and a limit capacity only (K – the maximum obtainable performance), their interaction was not implemented. Steenbeek and Van Geert's (2008; see also Van Geert & Steenbeek, 2005ab) agent model for the development of social interaction (used in this study to interpret our results; see Figure 2) may provide the necessary groundwork for future studies to implement models of interaction including both agents as well as different ToM dimensions and interactions. For example, the change in one variable will be related to the change in another variable in a bidirectional manner, which is a core characteristic of coupled systems.

In summary, the current study demonstrated that second-order ToM can be fitted by a dynamic rule and that when support was provided this seemed to compensate for the depletion of cognitive resources associated with performing second-order tasks, particularly for the prediction dimension. These results support the idea that environment and interactions among different ToM dimensions can be conceived as control parameters and implemented in a more complex dynamic system.

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M. Papera and P. Van Geert conceptualised the experiment. M. Papera carried out the study and the data analysis. A. Richards and M. Papera wrote this publication. Dr. Valentini Costanza contributed to the programming of the Strategic Games.

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