CORTEX 86 (2017) 205–215

Available online at www.sciencedirect.com

ScienceDirect

Journal homepage: www.elsevier.com/locate/cortex

Special issue: Note

# Does the way we read others' mind change over the lifespan? Insights from a massive web poll of cognitive skills from childhood to late adulthood

David Klindt [a], Marie Devaine [a] and Jean Daunizeau [a,b,*]

[a] Brain and Spine Institute (ICM), Paris, France
[b] Translational Neuromodelling Unit, ETH, Zurich, Switzerland

ARTICLE INFO

*Article history:*
Received 1 February 2016
Reviewed 2 March 2016
Revised 11 July 2016
Accepted 9 September 2016
Published online 23 September 2016

*Keywords:*
Theory of mind
Dual process theory
Cognitive control
Executive functions
Cognitive development
Cognitive decline

ABSTRACT

Mentalizing or Theory of Mind (ToM), i.e., the ability to recognize what people think or feel, is a crucial component of human social intelligence. It has been recently proposed that ToM can be decomposed into automatic and controlled neurocognitive components, where only the latter engage executive functions (e.g., working memory, inhibitory control and task switching). Critical here is the notion that such dual processes are expected to follow different developmental dynamics. In this work, we provide novel experimental evidence for this notion. We report data gathered from about thirty thousand participants of a massive web poll of people's cognitive skills, which included ToM and executive functions. We show that although the maturation of executive functions occurs in synchrony (around 20 years of age), this is not the case for different mentalizing competences, which either mature before (for elementary ToM constituents) or after (for higher-level ToM). In addition, we show that inter-individual differences in executive functions predict variability in higher-level ToM skills from the onset of adulthood onwards, i.e., after the complete maturation of executive functions. Taken together, these results indicate that the relative contribution of ToM's controlled component significantly changes with age. In particular, this implies that, over the lifespan, people may rely upon distinct cognitive architectures when reading others' minds.



## 1. Introduction

How do you know what others think or feel? Mentalizing or Theory of Mind (ToM), i.e., the ability to identify covert mental states from the interpretation of overt social signals (ranging from eye gazes and facial expressions to behavior and language), is a crucial component of human social intelligence (Frith & Frith, 2012). This is because ToM endows humans with highly adaptive social skills such as bonding, teaching or deceiving, whose sophistication is arguably unique within the animal kingdom (Call & Tomasello, 2008; Penn & Povinelli, 2007). But how stable is the cognitive architecture that

* *Corresponding author*. Motivation, Brain and Behaviour Group, Brain and Spine Institute, 47, bvd de l'Hopital, 75013, Paris, France.
E-mail address: jean.daunizeau@gmail.com (J. Daunizeau).
http://dx.doi.org/10.1016/j.cortex.2016.09.009

enables people to read others' mind over the lifespan? In particular: does the contribution of executive functions (e.g., working memory, inhibitory control, etc…) to mentalizing abilities change from childhood to late adulthood? These are the questions we address in this work.

Understanding others' mental states is a developing ability, whose most elementary constituents are acquired during early childhood (Wellman, Cross, & Watson, 2001). This development starts early, since children in their second year of life already show signs of surprise when others do not behave in accordance with their beliefs (Onishi & Baillargeon, 2005). This is taken as evidence of children's insight that people's behavior is driven by their beliefs rather than by physical reality, even if these beliefs happen to be false. ToM's sophistication then culminates at adulthood, when it engages a specific large-scale brain network, typically including the precuneus, the temporo-parietal junction and the medial prefrontal cortex (Gallagher & Frith, 2003; Van Overwalle & Vandekerckhove, 2013). This is not to say, however, that ToM is a monolithic cognitive ability. We know from dissociations observed in patients (e.g., autism spectrum disorder or Williams syndrome) that ToM can be decomposed into distinct cognitive subcomponents (Senju, Southgate, White, & Frith, 2009; Tager-Flusberg & Sullivan, 2000). We also know that mentalizing competences vary greatly between neurotypical adults and show weak inter-task correlations (Ferguson & Austin, 2010; Flobbe, Verbrugge, Hendriks, & Krämer, 2008; Lebreton, Kawa, d'Arc, Daunizeau, & Pessiglione, 2012). In fact, variations in the volume of elements of the ToM brain network predict inter-individual differences in distinct mentalizing tasks (Cullen, Kanai, Bahrami, & Rees, 2014; Hooker, Bruce, Lincoln, Fisher, & Vinogradov, 2011; Lewis, Rezaie, Brown, Roberts, & Dunbar, 2011). In addition, it has been shown that performances in various mentalizing tasks are correlated with measures of working memory and inhibitory control (Carlson & Moses, 2001; German & Hehman, 2006; Gordon & Olson, 1998). The contribution of such domain-general executive functions has been further evidenced by experimental studies demonstrating that some sophisticated mentalizing processes are disrupted by the concurrent engagement in secondary cognitively-demanding tasks (Apperly, Samson, & Humphreys, 2009; Bull, Phillips, & Conway, 2008; Lin, Keysar, & Epley, 2010; Qureshi, Apperly, & Samson, 2010). This multi-faceted portrait is compatible with a dual process theory of ToM (Frith & Frith, 2008). In brief, this theory suggests that full-grown mentalizing relies on both specialized representational skills (the ability to represent mental states as such) as well as executive resources for goal-oriented (i.e., task-related) processing of these representations (German & Hehman, 2006). Over the course of development, the representational system specializes for tracking mental states in an automatic, fast and efficient way. Its elementary constituents are expected to mature much before cognitive control, which enables the flexible allocation of executive resources. In this view, mind-reading is analogous to text-reading, in that an increasing part of its constituent cognitive processes (such as visual word recognition) become implicit and automatic as people grow older (Heyes & Frith, 2014). Would this idea hold true, it would imply that different ToM competences would be based upon qualitatively distinct cognitive architectures, whose relative contribution to mind reading may change with age.

In this work, we provide preliminary evidence that supports and extends this notion. We report data gathered from the BRAiN'US project, a free smartphone app that allows us to perform a massive web poll of some specific set of people's cognitive skills (https://sites.google.com/site/brainusapp2/). Here, we summarize the performance results in six games, which were designed to assess increasingly sophisticated mentalizing abilities (see below) and distinct executive functions (working memory, inhibitory control and task switching), respectively. In brief, we segmented our large sample into 16 age groups, ranging from 5 to 85 years old (age bin span = 5 years). We then quantified the lifespan dynamics of both mean performances and statistical interdependencies among these. The former allows to quantifying the time course of development and decline of investigated cognitive functions. The latter enable us to directly assess age-related changes in the contribution of executive functions to mentalizing abilities.

## 2. Methods

Recruitment of participants was performed through the smartphone/internet BRAiN'US platform (https://sites.google.com/site/brainusapp2/). This study was approved by a non-governmental ethics committee for academic research (CPP – Ile de France 1) on the 29th of July 2014, and was declared to the CNIL (i.e., the French national commission on informatics and liberties), under the name "massive web poll of the population's cognitive skills". Accordingly, participants were informed about the objectives and context of the project, and their consent was sought at the time of registration and then prior to engaging in each test. Data were then recorded on an anonymous and secure web database, along with biographical information including age, gender, place of residence, educational level and mental health status (under participants' conditional acceptance). All statistical data analyses were performed using the VBA freeware (Daunizeau, Adam, & Rigoux, 2014).

Subjects could play any of the BRAiN'US games in any order (although presentation order was randomized across subjects), and they could freely call off the experiment at any point. Before the beginning of each test, subjects were provided with written instructions accompanied with graphical summaries of the task. They then went through a training phase (which they could repeat as many times as they wanted). Feedback on their performance was provided at the end of each game. In this short note, we analyze performance data in the following six games:

- "*Emily and the donuts*" (*FB*): This is a variant of a false-belief task (1 trial), which evaluates one's ability to distinguish one's beliefs from others' beliefs (Wimmer & Perner, 1983). It can be seen as one of the most elementary constituent of ToM. Performance in this test is binary (correct *vs* incorrect answer).