Mycoplasma pneumoniae IgG positivity is associated with tic severity in chronic tic disorders
Schnell, Jaana; Bond, Molly; Moll, Natalie; Weidinger, Elif; Burger, Bianka; Bond, Rod; Dietrich, Andrea; Hoekstra, Pieter J; Schrag, Anette; Martino, Davide

Published in:
Brain, Behavior, and Immunity

DOI:
10.1016/j.bbi.2021.10.012

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version
Publisher's PDF, also known as Version of record

Publication date:
2022

Link to publication in University of Groningen/UMCG research database

Citation for published version (APA):

Copyright
Other than for strictly personal use, it is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license (like Creative Commons).

The publication may also be distributed here under the terms of Article 25fa of the Dutch Copyright Act, indicated by the “Taverne” license. More information can be found on the University of Groningen website: https://www.rug.nl/library/open-access/self-archiving-pure/taverne-amendment.

Take-down policy
If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from the University of Groningen/UMCG research database (Pure): http://www.rug.nl/research/portal. For technical reasons the number of authors shown on this cover page is limited to 10 maximum.

Download date: 16-09-2023
Mycoplasma pneumoniae IgG positivity is associated with tic severity in chronic tic disorders

Jaana Schnell a,2, Molly Bond b,2, Natalie Moll c, Elif Weidinger a, Bianka Burger d, Rod Bond e, Andrea Dietrich f, Pieter J. Hoekstra f, Anette Schrag g, Davide Martino h,i, Markus Schwarz c, Ute-Christiane Meier c,j, Norbert Müller a,*

a Department of Psychiatry and Psychotherapy, University Hospital, LMU Munich, Germany
b Blizard Institute, Queen Mary University of London, Barts and The London School of Medicine and Dentistry, Department of Neuroscience and Trauma, UK
c Institute of Laboratory Medicine, University Hospital, LMU Munich, Germany
d Marion von Tessin Memory-Zentrum, Munich, Germany
e University of Sussex, Brighton, UK
f University of Groningen, University Medical Center Groningen, Department of Child and Adolescent Psychiatry, Groningen, The Netherlands
g University College London, Institute of Neurology, London, UK
h Department of Clinical Neuroscience, Cumming School of Medicine, University of Calgary, Calgary, Canada
i Hotchkiss Brain Institute, Calgary, Canada
j Department of Psychological Medicine, Institute of Psychiatry, King’s College London, London, UK

ARTICLE INFO
Keywords:
- Tourette syndrome
- Chronic tic disorder
- Mycoplasma pneumoniae
- Infection
- Tic severity

ABSTRACT
Infectious pathogens may represent an environmental risk factor for chronic tic disorders (CTD). This cross-sectional study aimed to determine whether Mycoplasma pneumoniae (M. pneumoniae) IgG positivity is associated with the presence or severity of tics. We compared M. pneumoniae IgG positivity across three groups: children and adolescents (3–16 years) with CTD (CTD group; n = 302); siblings (3–10 years) of people with CTD who developed tics within a seven-year follow-up period (tic onset group; n = 51); siblings (4–10 years) who did not develop tics within the study period and were ≥10-years-old at their last assessment (unaffected group; n = 88). The relationship between M. pneumoniae IgG positivity and the presence and severity of tics was analysed using multilevel models controlling for site, family relatedness, sex, age, presence of comorbid obsessive-compulsive and/or attention-deficit/hyperactivity disorder and use of psychotropic medication. M. pneumoniae IgG positivity was not associated with the presence of CTD, or the first onset of tics as compared to siblings who remained unaffected. M. pneumoniae IgG positivity was associated with a higher tic severity score within the CTD group (β = 2.64, s.e. = 1.15, p = 0.02). It is possible that M. pneumoniae infection influences tic severity in CTD or, that having more severe tics, increases the risk of infection. However, it is more likely that the association observed in this study reflects a propensity toward enhanced immune responses in people with CTD and that, rather than a causal relationship, infection and greater tic severity are indirectly linked via shared underlying immune mechanisms.

1. Introduction
Chronic tic disorders (CTD) are common neurodevelopmental conditions characterised by the presence of motor tics, vocal tics or the combined presence of both known as Tourette syndrome (TS) (American Psychiatric Association, 2013). TS has an estimated worldwide prevalence of 0.3–0.9% (Knight et al., 2012). The aetiology of CTD is not fully understood. While there is a strong genetic component, with estimates of heritability between 0.25 and 0.77 (Mataix-Cols et al., 2015; Zilhão et al., 2017), environmental factors also play a substantial role (Hoekstra et al., 2013; Robertson et al., 2017).

Prior studies have suggested infectious agents may be involved in the pathogenesis of at least a subgroup of patients with CTD (Krause and Müller, 2012; Martino et al., 2020; Martino et al., 2015). Research

* Corresponding author.
† The EMTICS collaborative group.
2 Joint first authors.

https://doi.org/10.1016/j.bbi.2021.10.012
Received 27 May 2021; Received in revised form 23 September 2021; Accepted 19 October 2021
Available online 24 October 2021
0889-1591/© 2021 Published by Elsevier Inc.
focused on infections with Group A β-haemolytic streptococci (GBS) given their apparent role in related movement disorders such as Sydenham’s chorea and the post-streptococcal syndrome of tics and/or obsessive–compulsive disorders (OCD) termed PANDAS (paediatric autoimmune neuropsychiatric disorders associated with streptococcal infections) (Murphy et al., 2010; Orefici et al., 2016; Swedo et al., 1998). However, Martino and colleagues conducted a prospective cohort study of 715 children and adolescents diagnosed with CTD and could not find any association between recent exposure to Group A streptococcus and clinically relevant exacerbations of tics (Martino et al., 2021).

Associations between tics and other infectious pathogens including *Mycoplasma pneumoniae* (M. pneumoniae) (Dehning et al., 2009; Müller et al., 2004; Müller et al., 2000), *Borrelia burgdorferi* (Riedel et al., 1998), *Toxoplasma gondii* (Akaltun et al., 2018), and *Chlamydia trachomatis* (Krause et al., 2012) have been described in case reports and a few small-scale case-control studies. *M. pneumoniae* has also been linked to obsessive–compulsive (OC) symptoms (Erkan et al., 2008) and to movement disorders and/or basal ganglia lesions following *M. pneumoniae* encephalitis (Beskind and Keim, 1994; El Hafidi et al., 2012). In addition, one case-control study (n = 29) and case reports have suggested that infection with *M. pneumoniae* is associated with tics (Dehning et al., 2009; Müller et al., 2004; Müller et al., 2000). However, the salience of these observations is yet to be elucidated. *M. pneumoniae* is a ubiquitous infectious agent that generally causes a mild acute respiratory infection (Atkinson et al., 2008). The prevalence of *M. pneumoniae* IgG positivity, which is most likely due to past infection, is around 12% in early childhood and increases to 50–60% in adolescence with no significant difference between sexes (Tuuminen et al., 2000). *M. pneumoniae* infection tends to be either asymptomatic or a self-limiting illness. However, it is also a common cause of community-acquired pneumonia and extrapulmonary manifestations can affect any organ, including the brain (Korpi et al., 2004).

The mechanisms underpinning a possible role for infections in CTD are not fully understood. A number of studies have reported altered innate and adaptive immune responses in people with CTD (Martino et al., 2015) with increased serum levels of pro-inflammatory cytokines (Leckman et al., 2005), changes in regulatory T-cells responses (Kawi-kova et al., 2007) and activation of microglial cells (Lennington et al., 2016). It may be that infections facilitate an immune activation that enhances behavioural changes through direct effects on the central nervous system, such as via cytokines (Leckman et al., 2005) or anti-bodies (Bombaci et al., 2009; Krause et al., 2010; Martino et al., 2011; Martino et al., 2015). An autoimmune mechanism induced by molecular mimicry, with a similar aetiology to Sydenham’s Chorea, has also been hypothesized for a subset of those with CTD (Hockstra et al., 2002; Snider and Swedo, 2003). Alternatively, individuals with CTD may be more susceptible to infections because of a primary immune dysregulation (Martino et al., 2020; Martino et al., 2015).

Therefore, this study sought to determine whether past infection with one infectious agent of interest, *M. pneumoniae*, was associated with the presence of CTD, the first onset of tics or tic severity. This is a cross-sectional study that used sub-samples of the European Multicentre Tics in Children Studies (EMTICS) cohorts based on available serum samples for analysis of *M. pneumoniae* IgG positivity. EMTICS is a large prospective European multicentre study of children and adolescents with CTD (Schrag et al., 2019). This study investigated whether: (A) children with CTD have higher rates of *M. pneumoniae* IgG positivity compared to unaffected siblings; (B) the rate of baseline *M. pneumoniae* IgG positivity is higher in siblings who developed tics compared to those who did not develop tics; and (C) *M. pneumoniae* IgG positivity is associated with higher tic severity in participants with CTD. To our knowledge, this is the largest study to investigate *M. pneumoniae* IgG in CTD and is unique in its assessment of serum IgG positivity prior to the development of tics in an at-risk cohort.

2. Participants and methods

2.1. Participants

Participants were drawn from the EMTICS study, a prospective observational cohort study that aimed to assess the contribution of genetic and environmental risk factors in CTD (Schrag et al., 2019). Data were collected by 16 (child and adolescent) psychiatry and paediatric neurology outpatient clinics across Europe and in Israel. The EMTICS project was based on two separate cohort studies: the COURSE study, including children and adolescents (3–16 years) with a diagnosis of CTD according to DSM-IV-TR (American Psychiatric Association, 2000), and the ONSET study, an at-risk cohort of first-degree relatives, mostly siblings, of children with CTD (3–10 years) without tics, OCD or trichotillomania. The ONSET cohort was followed up bimonthly for up to three years to assess the onset of tics according to study protocol. All unaffected children were re-assessed and the majority were re-assessed via a brief telephone interview after the study ended. The regular study period took place between 2013 and 2018, with the final telephone reassessment concluded in May 2020.

The mean age of tic onset in the ONSET cohort was 7.9 years (SD 2.0, range 3.5–13.0); we therefore excluded those who were younger than 10-years-old at the time of their last assessment and had not developed any tics from the unaffected at-risk comparison group (unaffected group) to reduce the likelihood of including children who might still develop tics.

Exclusion criteria for participants in both COURSE and ONSET cohorts included treatment with antibiotics during the last month (since a separate antibiotic study was part of the research plan), a serious medical or neurological illness or an inability to understand and implement given study procedures (Schrag et al., 2019).

The current cross-sectional study used data from sub-samples of the EMTICS cohorts (COURSE and ONSET) at a single time point: at baseline for those with an existing tic disorder and for first-degree relatives who did not develop tics and at the time of tic onset for those who developed tics within the study. Schrag and colleagues described the sample size calculation for the EMTICS project for both the COURSE and ONSET cohorts (Schrag et al., 2019). The assessment of *M. pneumoniae* IgG was included in the original research plan of EMTICS as a secondary measure. Therefore, the sub-samples in this study comprised all participants for whom we had serum available to measure *M. pneumoniae* IgG. Rates of *M. pneumoniae* IgG positivity were compared across three groups: 302 participants with CTD from the COURSE cohort (CTD group); 51 first-degree relatives (all siblings) who developed tics within the seven-year total study period from the ONSET cohort (tic onset group); and 88 unaffected first-degree relatives (all siblings) who were ≥10 years old at time of their last assessment from the ONSET cohort (unaffected group). The study was approved by the Institutional Review Boards of all clinics involved. Furthermore written informed consent and assent was collected by the parents and their children.

2.2. Clinical measures

Participants in the COURSE cohort had an established diagnosis of CTD (TS, chronic motor tic disorder or chronic vocal tic disorder), which was confirmed by trained clinicians using DSM-IV-TR criteria at baseline (American Psychiatric Association, 2000), as was the possible presence of comorbid OCD and attention-deficit/hyperactivity disorder (ADHD). Baseline tic severity was measured using the Yale Global Tic Severity Scale (YGTS) (Leckman et al., 1989), which provides the Total Tic Severity Score (range 0–50) comprised of two subscales: YGTS Motor Tic Severity Score (range 0–25) and YGTS Vocal Tic Severity Score (range 0–25). In addition, the Clinical Global Impression Severity (CGI-S) Scale (Guy, 1976) was used to assess tic severity during the previous week. Participants in the ONSET cohort suspected of having developed tics were assessed by study clinicians and the onset of tics was confirmed.
according to DSM-IV-TR criteria (American Psychiatric Association, 2000). Use of psychotropic medication during the last two weeks was documented by the study clinicians.

2.3. Laboratory measures

Samples were sent to the Department of Laboratory Medicine, Munich (LMU) and stored at -80 °C until analysis. Serum IgG against M. pneumoniae were measured in the ISO 15189 accredited lab on a DiaSorin Liaison analyser using Chemiluminescence Immunoassay with paramagnetic microparticle solid phase (CLIA) technology; the analyser range was 1–200 AU/ml. M. pneumoniae elicits antibody responses after around one week of illness. This is initially an IgM response before seroconversion to IgG; serum IgG tends to peak at 3–6 weeks, before it gradually declines (Atkinson et al., 2008). IgG tends to remain elevated in children for around four years following infection but can also persist indefinitely (Daxboeck et al., 2003; Jacobs et al., 1986; Foy et al., 1977).

Serum IgG ≥10 AU/ml was considered positive for previous infection with M. pneumoniae at any point in time and <10 AU/ml as negative (Waris et al., 1998; Almasri et al., 2011). IgG positivity is most likely due to past, rather than acute, infection with M. pneumoniae and does not provide information on how recently the participant was infected.

2.4. Statistical analysis

Clinical data of the three groups were described by mean values and standard deviations or percentages, according to the type of variable. The primary predictor variable for all our analyses was baseline serum M. pneumoniae IgG positivity (0 = absence, 1 = presence). We used generalised linear mixed models to assess whether IgG positivity was associated with i) having a CTD compared to the unaffected group; or ii) tic onset compared to the unaffected group. In addition, we used linear mixed-effects models to determine whether iii) IgG positivity was associated with tic severity within the CTD group. Since this is a multicentre study involving siblings, we used multilevel models with both site and family relatedness as cluster variables. Sex, age, the presence of a comorbidity (OCD and/or ADHD) and the use of psychotropic medication in the past two weeks were entered as covariates. We controlled for comorbid OCD and ADHD as these are common comorbidities in CTD (Freeman et al., 2000) and have both also been linked to infections (Ercan et al., 2008; Leslie et al., 2008) and immune dysfunction (Gabbay et al., 2009; Hoekstra, 2019). Likewise, we controlled for psychotropic medication use as some psychotropic medications have anti-inflammatory properties that could affect seropositivity (Lind and Kristiansen, 2000).

Age and sex varied substantially between groups and both were significant predictors of tics, though not M. pneumoniae IgG positivity. We therefore also conducted a sensitivity analysis with age and sex matched subgroups (CTD group versus unaffected group n = 88; tic onset group versus unaffected group n = 51) using propensity score matching in R (Randolph et al., 2014).

3. Results

3.1. Study cohort

Baseline demographic and clinical characteristics of participants are shown in Table 1. The vast majority of the CTD cohort was diagnosed with TS (n = 274, 90.73%), 26 (8.61%) had a chronic motor tic disorder and 2 (0.66%) a chronic vocal tic disorder. The average time between baseline and tic onset in the tic onset group was 1.1 years (range 0.1–5.4 years) and therefore elevation of IgG would be expected to persist during this time. Increasing age was significantly associated with M. pneumoniae IgG seropositivity in the tic onset group (p = 0.04) but not in the CTD or unaffected groups and there was no significant association with sex among any of the groups (Supplementary materials, Table 2).

### Table 1

Baseline Demographics and Clinical Characteristics.

<table>
<thead>
<tr>
<th></th>
<th>CTD group (n = 302)</th>
<th>Tic onset group (n = 51)</th>
<th>Unaffected group (n = 88)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (range) (mean ± SD)</td>
<td>4.5–16.99</td>
<td>11.0 ± 2.7</td>
<td>3.2–10.6</td>
</tr>
<tr>
<td>Sex n (%)</td>
<td>235</td>
<td>20.8%</td>
<td>62</td>
</tr>
<tr>
<td>Male</td>
<td>22.2%</td>
<td>21</td>
<td>52</td>
</tr>
<tr>
<td>Female</td>
<td>90.7%</td>
<td>41.2%</td>
<td>59.1%</td>
</tr>
<tr>
<td>Chronic tic disorder (CTD) n (%)</td>
<td>274</td>
<td>8.6%</td>
<td>2</td>
</tr>
<tr>
<td>Tourette syndrome (TS)</td>
<td>26</td>
<td>0.7%</td>
<td>2</td>
</tr>
<tr>
<td>Chronic motor tic disorder</td>
<td>2</td>
<td>3.4%</td>
<td>2</td>
</tr>
<tr>
<td>Chronic vocal tic disorder</td>
<td>2</td>
<td>3.4%</td>
<td>2</td>
</tr>
<tr>
<td>Tic severity (range) (mean ± SD)</td>
<td>0–44</td>
<td>20.1 ± 8.3</td>
<td>0–23</td>
</tr>
<tr>
<td>YGTTS Total</td>
<td>0–23</td>
<td>12.8 ± 4.5</td>
<td>0–21</td>
</tr>
<tr>
<td>YGTTS Motor</td>
<td>0–21</td>
<td>7.4 ± 5.4</td>
<td>1–6</td>
</tr>
<tr>
<td>YGTTS Vocal</td>
<td>1–6</td>
<td>3.6 ± 0.9</td>
<td>3</td>
</tr>
<tr>
<td>Psychotropic drug treatment during the previous 2 weeks n (%)</td>
<td>108</td>
<td>35.8</td>
<td>3</td>
</tr>
<tr>
<td>Comorbidities n (%)</td>
<td>OCD</td>
<td>28.5</td>
<td>3.2</td>
</tr>
<tr>
<td>ADHD</td>
<td>76</td>
<td>25.2</td>
<td>4</td>
</tr>
<tr>
<td>M. pneumoniae IgG positivity n (%)</td>
<td>48</td>
<td>15.9</td>
<td>9</td>
</tr>
</tbody>
</table>

Note. Unaffected group, did not develop tics and ≥10 years old at last assessment; OCD, obsessive-compulsive disorder; ADHD, attention-deficit/hyperactivity disorder; M. pneumoniae IgG, ≥10 AU/ml was considered positive.

<table>
<thead>
<tr>
<th>Dependent variable (covariates)</th>
<th>OR</th>
<th>95% CI</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTD group versus unaffected</td>
<td>0.71</td>
<td>0.29–1.75</td>
<td>0.45</td>
</tr>
<tr>
<td>M. pneumoniae IgG positivity</td>
<td>0.19</td>
<td>0.15–2.38</td>
<td>&lt;0.01*</td>
</tr>
<tr>
<td>Age</td>
<td>2.18</td>
<td>1.58–3.06</td>
<td>&lt;0.01*</td>
</tr>
<tr>
<td>Sex</td>
<td>0.17</td>
<td>0.08–0.36</td>
<td>0.02*</td>
</tr>
<tr>
<td>Comorbidity (OCD and/or ADHD)</td>
<td>3.23</td>
<td>1.23–8.49</td>
<td>0.02*</td>
</tr>
<tr>
<td>Psychotropic medication</td>
<td>3.89</td>
<td>0.82–18.41</td>
<td>0.09</td>
</tr>
</tbody>
</table>

Note. GLM (generalised linear mixed model) with age, sex, comorbidity (OCD and/or ADHD) and psychotropic medication as covariates was used. The presence of either or both ADHD and/or OCD was entered as a single covariate (absence = 0, presence = 1). CTD group, Chronic tic disorder group: COURSE children; Unaffected group: ONSET children who did not develop tics by end of the study or re-assessment and ≥10 years old. *p < 0.05.
and Figs. 1–3 histograms show the distribution of seropositivity by age for each group).

3.2. Previous infection is not associated with higher odds of tics

*M. pneumoniae* IgG positivity was not associated with either having CTD in the CTD group when compared to the unaffected group (p > 0.05) (as shown in Table 2), or tic onset in the tic onset group when compared to the unaffected group (p > 0.05) (as shown in Table 3). These results remained non-significant (p > 0.05) when we conducted a sensitivity analysis with age and sex matched groups (Supplementary material in Table 1).

Older age (p < 0.01), male sex (p < 0.01), and the presence of a comorbidity (OCD and/or ADHD; p < 0.05) were all significantly associated with having a CTD compared to the unaffected group (Table 2), whilst only older age was significantly associated with the onset of tics compared to the unaffected group (p < 0.05) (Table 3).

3.3. *M. pneumoniae* IgG positivity was associated with tic severity in CTD group

The association between seropositivity and tic severity is shown in Table 4. The presence of IgG antibodies against *M. pneumoniae* was associated with a higher YGTSS Total Tic Severity Score (β = 2.64, s.e. = 1.15, p = 0.02). There was a significant association between *M. pneumoniae* IgG positivity and the YGTSS Vocal Tic Severity Score (β = 1.02, s.e. = 0.62, p = 0.03) but no association with the CGI-S (see Table 4).

4. Discussion

The main finding of this multicentre study in children and adolescents with tics disorders was that *M. pneumoniae* IgG positivity was not associated with a diagnosis of CTD or tic onset in a prospective at-risk cohort. *M. pneumoniae* IgG positivity, however, was associated with higher tic severity in children and adolescents with established CTD.

In the current study, infection rates of *M. pneumoniae* were no higher among those with tics than those without. Seropositivity rates among all groups in this study were lower than those reported elsewhere in the general population (Atkinson et al., 2008; Tuuminen et al., 2000). The reasons for this observation are not clear. Spread of *M. pneumoniae* among children is thought to increase with early day-care and school attendance; in spring and autumn; as well as during cyclic epidemics that tend to occur every 3–5 years (Atkinson et al., 2008). Reduced school attendance because of medical appointments and fewer regional epidemics may partially account for the lower rates seen in our study population but neither fully explains the marked difference we observed. Another unexpected finding was that rates *M. pneumoniae* IgG positivity were evenly distributed by age across the groups (see Supplementary materials Figs. 1–3) and seropositivity was only associated with age in the tic onset group and not the CTD or unaffected groups. *M. pneumoniae* IgG positivity persists in the serum for a long-time following infection (estimates of around 4 years but can be indefinite (Daxboeck et al., 2003; Jacobs et al., 1986; Foy et al., 1977)), therefore, IgG positivity rates tend to increase with age during childhood: one population-based study found the incidence of IgG positivity to increase from 12% in pre-school children to 50–60% in adolescents (Tuuminen et al., 2000). One reason why we may not have observed an association with age in this study might have been because only a relatively small number of participants from each group were found to be seropositive, thus reducing the power and likelihood of observing a significant association. Nonetheless, given the strong association between age and seropositivity reported in the literature and a significant association in the tic onset group, we adjusted for age in all our models and conducted sensitivity analysis with age and sex matched subgroups.

We observed no association between *M. pneumoniae* IgG positivity and the presence of a CTD or the first onset of tics. The only previous study of *M. pneumoniae* in TS found elevated IgA, but not IgG, in 29 individuals with TS (6–60 years of age) compared to healthy controls (Müller et al., 2004). The authors proposed that this may be because *M. pneumoniae* IgA is particularly elevated in extra-pulmonary manifestations of *M. pneumoniae* infection (Müller et al., 2004). Due to lack of available serum for analysis, IgA was not measured in this study and should be considered in future research of suspected *M. pneumoniae* involvement in neuropsychiatric diseases. Nonetheless, our findings do not suggest that children with tics or children who will later go on to develop tics are particularly susceptible to *M. pneumoniae* infection or mount an unusually sustained response to the pathogen compared to people without tics.

*M. pneumoniae* IgG positivity was, however, associated with a higher YGTSS Total Tic Severity Score (range 0–50) of 2.64 points on average among participants with CTD after adjustments for age, sex, the presence of comorbid OCD and/or ADHD and use of psychotropic medication. This association between seropositivity and greater tic severity could reflect either a direct or indirect relationship. As this is a cross-sectional study that only measured IgG antibodies, indicative of past infection, at a single point in time, we cannot determine whether previous infection is associated with tic onset; whether infection coincides
with a worsening of symptoms; or whether a worsening of symptoms increases the risk of infection.

In the context of the existing literature on anti-infectious immune responses in CTD (Martino et al., 2020), it is more likely that seropositivity and greater tic severity are epiphenomena of a shared underlying mechanism, with neither directly influencing the other. Several studies have indicated that individuals with tic disorders have enhanced

![Fig. 2. Histogram of seropositivity by age in tic onset group. Note. Tic onset group: ONSET children with tic onset.](image)

![Fig. 3. Histogram of seropositivity by age in unaffected group. Note. Unaffected group: ONSET children who did not develop tics by end of the study or re-assessment and ≥10 years old.](image)

### Table 3

<table>
<thead>
<tr>
<th>Dependent variable (covariates)</th>
<th>OR</th>
<th>95% CI</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tic onset group versus unaffected group</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>M. pneumoniae</em> IgG positivity</td>
<td>1.74</td>
<td>0.61–4.97</td>
<td>0.30</td>
</tr>
<tr>
<td>Age</td>
<td>0.75</td>
<td>0.60–0.94</td>
<td>0.01*</td>
</tr>
<tr>
<td>Sex</td>
<td>0.54</td>
<td>0.24–1.17</td>
<td>0.12</td>
</tr>
<tr>
<td>Comorbid ADHD and/or OCD</td>
<td>0.54</td>
<td>0.13–2.17</td>
<td>0.38</td>
</tr>
<tr>
<td>Psychotropic medication</td>
<td>3.02</td>
<td>0.30–30.06</td>
<td>0.34</td>
</tr>
</tbody>
</table>

Note. GLM (generalised linear mixed model) with age, sex, comorbidity (OCD and/or ADHD) and psychotropic medication as covariates was used. The presence of either or both ADHD and/or OCD was entered as a single covariate (absence = 0, presence = 1). Tic onset group: ONSET children with tic onset; Unaffected group: ONSET children who did not develop tics by end of the study or re-assessment and ≥10 years old. *p < 0.05.

### Table 4

<table>
<thead>
<tr>
<th>Independent variable (dependent variable)</th>
<th>β</th>
<th>SE</th>
<th>95% CI</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>M. pneumoniae</em> IgG</td>
<td>2.64</td>
<td>1.15</td>
<td>0.38–4.89</td>
<td>0.02*</td>
</tr>
<tr>
<td>(YGTSS Total)</td>
<td>1.02</td>
<td>0.62</td>
<td>−0.21–2.24</td>
<td>0.10</td>
</tr>
<tr>
<td>(YGTSS Vocal)</td>
<td>1.71</td>
<td>0.78</td>
<td>0.18–3.24</td>
<td>0.03*</td>
</tr>
<tr>
<td>(CGI-S)</td>
<td>0.17</td>
<td>0.13</td>
<td>−0.09–0.44</td>
<td>0.20</td>
</tr>
</tbody>
</table>

Note. Linear mixed-effects models with age, sex, comorbidity (OCD and/or ADHD) and psychotropic medication as covariates were used. The presence of either or both ADHD and/or OCD was entered as a single covariate (absence = 0, presence = 1). YGTSS, Yale Global Tic Severity Scale [Total = Motor + Vocal Tic Severity Score (range 0–50)]; CGI-S, Clinical Global Impression Severity Scale; *p < 0.05.

responses in CTD (Martino et al., 2020), it is more likely that seropositivity and greater tic severity are epiphenomena of a shared underlying mechanism, with neither directly influencing the other.
immune-inflammatory responses, including stronger antibody responses (Bombaci et al., 2009; Krause et al., 2010; Martino et al., 2011), as well as positive correlations between greater tic severity and interleukin-2 (IL-2) (Bos-Veneman et al., 2011). Increased tumor necrosis factor (TNF)-α and interleukin-12 (IL-12) during tic or OC symptom exacerbation, regardless of pharmacological treatment, have been reported (Leckman et al., 2005). An upregulation in the expression of genes that control immune-modulating neurotransmitters has also been demonstrated (Tian et al., 2011a; Tian et al., 2011b; Gunther et al., 2012). In a recent review of immunological mechanisms in brain development and tic disorders, Martino and colleagues suggest that abnormal immune priming, most likely driven by a genetic predisposition interacting with environmental factors, may alter both the maturation of neural networks and immune regulatory mechanisms (Martino et al., 2020). Thereby, resulting in the co-occurrence of neurodevelopmental disorders (such as tic disorders) and hypersensitive immune responses to pathogens (such as to M. pneumoniae) (Martino et al., 2020).

A prospective longitudinal study described that a multiplicative interaction between GABHS infections and psychosocial stress can enhance tic and OC symptom severity (Lin et al., 2010). Psychosocial stress, a strong predictor of greater tic severity, may also influence immune responses to infection via activation of the hypothalamic-pituitary-adrenal axis (Martino et al., 2020), although this mechanism is yet not fully understood (Buse et al., 2021). Finally, behavioural patterns, which may be accentuated in young people with greater tic severity and/or a greater comorbid neuropsychiatric burden, could increase the risk of exposure to infectious pathogens (Martino et al., 2020) and, thus, also indirectly contribute the association observed in thus study.

5. Limitations and future directions

This study has a number of strengths: EMTICS recruited a large population of children and adolescents with CTD from multiple centres across Europe and in Israel. It is unique in its assessment of first-degree relatives as prospective at-risk cohort and these children were extensively followed up for a period of up to seven years to assess the possible onset of tics.

However, there were also some notable limitations. The main limitation is the lack of longitudinal data, which preclude any analysis of a temporal relationship or any inference regarding causality. As mentioned, measurements of M. pneumoniae IgA, in addition to IgG antibodies, would be useful given previous reports of particular elevation of IgA in extra-pulmonary manifestations of M. pneumoniae infection (Müller et al., 2004). There was also only a small number of available serum samples for the tic onset and unaffected cohorts and only a small proportion of each group were M. pneumoniae IgG positive, which reduced the likelihood of observing significant differences between groups. To elucidate the direction of causality, longitudinal data from patients with CTD and a healthy age- and sex-matched control group would be needed, ideally with regular (e.g., 4-monthly) clinical assessments and serum samples of pathogen titers (IgG, IgM, IgA), cytokines, and other immune effector molecules.

6. Conclusion

This is the largest cross-sectional study of M. pneumoniae infection in children and adolescents with CTD to date and the first to prospectively investigate M. pneumoniae infection in siblings in relation to the onset of tics. We found no evidence of an association between previous M. pneumoniae IgG positivity and the presence of CTD or first onset of tics. However, we did observe an association between M. pneumoniae IgG positivity and greater tic severity. It is possible that M. pneumoniae infection influences tic severity in CTD. Alternatively, greater disease severity may increase the risk of infection. However, it seems more likely that this observation reflects a propensity toward enhanced immune responses in people with CTD (as has been previously reported) and that greater tic severity and M. pneumoniae seropositivity share underlying mechanisms rather than a causal relationship. This is the first study to report this finding and further research into the relationship between infections and CTD may shed light on the mechanisms underlying disease onset, severity, and course.

Funding

This project has received funding from the European Union’s Seventh Framework Programme for research, technological development and demonstration under Grant agreement no. 278367. This research was further supported by the National Institute for Health Research Biomedical Research Centre at Great Ormond Street Hospital for Children NHS Foundation Trust and University College London (Heyman); the Owerko Foundation; the Spanish Ministry of Science and Innovation (RTC2019-007150-1), the Instituto de Salud Carlos III-Fondo Europeo de Desarrollo Regional [ISCIII-FEDER] [PI14/01823, PI16/01575, PI18/01898, PI19/01576], the Consejería de Economía, Innovación, Ciencia y Empleo de la Junta de Andalucía [CVI-02526, CTIS-7685], the Consejería de Salud y Bienestar Social de la Junta de Andalucía [PI-0471-2013, PE-0210-2018, PI-0459-2018, PE-0186-2019], and the Fundacion Alicia Koplowiz (Mir); the EU [FP7-HEALTH-2011 No. 278367, FP7-People-2012-ITN No. 316978] (Fremer and Müller-Vahl); the German Research Foundation [DFG: GZ MU 1527-3-1], the German Ministry of Education and Research [BMBF: 01KG1421], the National Institute of Mental Health (NIMH), and the Tourette Gesellschaft Deutschland e.V., the Else-Kroner-Fresenius-Stiftung (Müller-Vahl); the Posselh-Stiftung [Liibeck, Germany], Margot und Jüergen Wessel Stiftung [Liibeck, Germany], Tourette Syndrome Association [Germany], Interessenverband Tourette Syndrom [Germany], CHDI, Damp-Stiftung [Kiel, Germany]. Academic research support: Deutsche Forschungsgemeinschaft (DFG): projects 1692/3-1, 4-1, SFB 936, and FOR 2698 [project numbers 396914663, 396577296, 396474989]; and European Reference Network – Rare Neurological Diseases [ERN – RND; Project ID No 739510] (Münchau); and the National Institute for Health Research UCLH Biomedical Research Centre (Schrag).

Declaration of Competing Interest

Davide Martino has received honoraria for lecturing from the Movement Disorders Society, Tourette Syndrome Association of America and Dystonia Medical Research Foundation Canada; honoraria for advisory board attendance from Sunovion Pharmaceuticals Canada Inc.; research and education funding support from Dystonia Medical Research Foundation Canada, the University of Calgary, the Michael P Smith Family, the Owerko Foundation, Ipen Corporate, the Parkinson Association of Alberta and the Canadian Institutes for Health Research; royalties from Springer-Verlag. Kirsten Müller-Vahl has received financial or material research support from Abide Therapeutics, Almirall Hermal GmbH, GW pharmaceuticals, Lundbeck, Synoex Health, and Therapix Biosciences Ltd. She has received consultant’s honoraria from Abide Therapeutics, Allmiral, Boehringer Ingelheim International GmbH, Bionorica Ethics GmbH, Cannamedical Pharma GmbH, Canopy Growth, Columbia Care, CTC Communications Corp., Eurox Deutschland GmbH, Global Praxis Group Limited, IMC Germany, Lundbeck, Resalo Vertrieb GmbH, Sanity Group, STADAPHARM GmbH, Synendos Therapeutics AG, and Tilray. She is/was a consultant or advisory board member for Abide Therapeutics, The Academy of Medical Cannabis Limited, Altrio, Aphria Deutschland GmbH, Cannamedical Pharma GmbH, Bionorica Ethics GmbH, Cannaxan GmbH, Canopy Growth, Columbia Care, CTC Communications Corp., IMC Germany, Leafly Deutschland GmbH, Lundbeck, Nuvelution TS Pharma Inc., Resalo Vertrieb GmbH, Sanity Group, Syqe Medical Ltd., Therapix Biosciences Ltd., Tilray, Wayland Group, and CTC Communications Corporation.

286
She has received speaker’s fees from Aphria Deutschland GmbH, Cognitando GmbH, Emalex, Eurox Deutschland GmbH, Ever Pharma GmbH, PR Berater, Spectrum Therapeutics GmbH, Tilray, and Wayland Group. She has received royalties from Medizinisch Wissenschaftliche Verlagsgesellschaft Berlin, Elsevier, and Kohlhammer. Alexander Münchau received Royalties for the book Neurogenetics (Oxford University Press). Veit Roesner has received payment for consulting and writing activities from Lilly, Novartis, and Shire Pharmaceuticals, and Medice Pharma, and support for research from Shire and Novartis. He has carried out (and is currently carrying out) clinical trials in cooperation with the Novartis, Shire, and Otsuka companies. Annette Schrag has received consultative or advisory board honoraria from Biogen, Abbvie, Bial and Neurotechnology, research support from the National Institute of Health Research, Parkinson’s UK and the Economic and Social Research Council and the European Commission, and Royalties from Oxford University Press. Susanne Walitza has received in the last 5 years royalties from Thieme Hogrefe, Kohlhammer, Springer, Beltz. Her work was supported in the last 5 years by the Swiss National Science Foundation (SNF), diff. EU FP7, HSM Hochspecialisierte Medizin of the Kanton Zurich, Switzerland, Bfarm Germany, ZnEP, Hartmann Müller Stiftung, Olga Mayenfisch, Gertrud Thalmann, Vontobel, Unicentia, Erika Schwarz Fonds. Outside professional activities and interests are declared under the link of the University of Zurich www.uzh.ch/prof/sld/dir/interessen.bindungen/client/web/. On behalf of all other authors, the corresponding author declares that the other authors have no conflicts of interest.

Acknowledgements

The authors are deeply grateful to all children and their parents who willingly participated to make this research possible. We thank all colleagues at the various study centers who contributed to data collection: Julie E. Bruun, Judy Grejsen, Christiane L. Ommundsen, Mette Rubæk the last 5 years by the Swiss National Science Foundation (SNF), diff. EU FP7, HSM Hochspecialisierte Medizin of the Kanton Zurich, Switzerland, Bfarm Germany, ZnEP, Hartmann Müller Stiftung, Olga Mayenfisch, Gertrud Thalmann, Vontobel, Unicentia, Erika Schwarz Fonds. Outside professional activities and interests are declared under the link of the University of Zurich www.uzh.ch/prof/sld/dir/interessen.bindungen/client/web/. On behalf of all other authors, the corresponding author declares that the other authors have no conflicts of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.bbi.2021.10.012.

References


