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Does Asthma Disturb Executive Functions and Self-regulation in Children?

Abstract

Due to possible psychosocial and neurocognitive factors, asthma may present a risk to children's executive functions and self-regulation, especially when it is poorly controlled. One hundred and one 8-11 year-old children (patients with asthma, ADHD and healthy peers) and their parents participated in the study. Four cognitive tasks measuring different executive functions and parent and child versions of behavior regulation inventory were used. Children with asthma had more difficulties shifting their attention between tasks and exhibited more problems in self-regulation than their healthy peers, but their scores were better than children with ADHD. Patients with more intensive treatment, poor symptom control, a history of acute asthma attacks and non-compliance had slightly more difficulties in executive functions and self-regulation.

Key words: asthma, symptom control, executive functions, self-regulation

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Abstrakt

Ze względu na działanie czynników psychospołecznych i neuropoznawczych, astma może stanowić ryzyko dla sprawności funkcji wykonawczych i samoregulacji dzieci, szczególnie gdy jest niewystarczająco kontrolowana. W badaniu wzięło udział 101 dzieci w wieku 8-11 lat (chorych na astmę, ADHD i zdrowych) wraz z rodzicami. Do pomiaru czterech funkcji wykonawczych zastosowano zadania komputerowe, a do pomiaru samoregulacji - inwentarz regulacji zachowania w wersji dla rodziców oraz dla dzieci. Dzieci chore na astmę przejawiały więcej trudności w przełączaniu uwagi między zadaniami oraz więcej problemów w zachowaniu niż ich zdrowi rówieśnicy, mniej jednak niż dzieci z ADHD. Pacjenci z gorszą kontrolą objawów astmy, historią ostrych napadów duszności, intensywniej leczeni i nieprzestrzegający zaleceń lekarskich charakteryzowali się nieco mniejszą sprawnością funkcji wykonawczych i samoregulacji.

Słowa kluczowe: astma, kontrola objawów, funkcje wykonawcze, samoregulacja

Introduction

Asthma is the most common chronic inflammatory disorder, the prevalence of which is increasing in most countries, especially among children (GINA Report, 2008). This chronic inflammation is associated with airway hyperresponsiveness, which leads to recurrent episodes of wheezing, breathlessness, chest tightness and coughing. When uncontrolled, asthma can significantly limit a child's ability to play, learn and sleep. In clinical child psychology, cognitive functioning and self-regulation in children with asthma is a subject of interest for several reasons. Firstly, it is known that environmental and illness-related stressors may influence the self-regulatory skills of children and families alike, and these are crucial for proper asthma management (McQuaid colleagues, 2008). Secondly, the possibility of neuroendocrine disturbances and mild intermittent hypoxia raises questions about children's cognitive functioning in some asthma cases (Priftis and colleagues, 2008; Bass, Corwin and colleagues, 2004).

Cognitive functioning and self-regulation in children with asthma

Since asthma became a disorder whose clinical manifestations could be controlled effectively (GINA Report, 2006), the risk of serious intellectual deficits among children with asthma has fallen significantly. In a large study on cognitive functioning in children with mild and moderate asthma, R. Annett and colleagues (2000) demonstrated that there were no differences in general IQ scores and memory tests between patients with asthma and healthy children. However, children with asthma were less efficient in tasks measuring elementary (vigilance, sustained attention) and executive (interference control) aspects of attention, which may be a manifestation of problems with behavioral control. In further studies several authors confirmed that children with asthma manifest difficulties with emotion regulation and behavioral control, especially when the illness is poorly controlled (McQuaid and colleagues, 2001; Reichenberg and colleagues, 2004; Halterman and colleagues, 2006; Meuret and colleagues, 2006; Goldbeck and colleagues, 2007). M. Klinnert and E. McQuaid (2001) demonstrated that 1) parents of children with asthma observe more problems in their behavior than parents of healthy peers, 2) children do not report such problems when completing self-report questionnaires, 3) children with poorly controlled asthma manifest more disturbances in emotion regulation during tasks done with an experimenter. Furthermore, it has been confirmed that more anxiety, attention and conduct disorders, ADHD and learning difficulties are diagnosed among patients with asthma (Goodwin and colleagues, 2004; Blackman and colleagues, 2007; Arif, 2010). E. McQuaid and colleagues (2008) as well as H. Yuksel and colleagues (2008) revealed that children with asthma had poorer vigilance and sustained attention while their parents observed some symptoms of hyperactivity and impulsivity in their behavior, especially when the illness was not sufficiently controlled. Because the aforementioned studies used questionnaires for parents of children with ADHD to assess behavioral disturbances in patients with asthma, further research is needed to determine how much the children with poorly controlled asthma are similar to those with ADHD.

Why asthma may be associated with disturbances in attention and self-regulation

Although it is unclear why asthma may be associated with disturbances in a child's cognition and behavior, several explanations can be suggested. Firstly, a child's self-regulation can be influenced by the quality of symptom control (Klinnert and McQuaid, 2001). A child with poorly controlled asthma as well as its parents may experience greater anxiety due to unpredictability of the illness (eg. fear of asthma attacks) or be less compliant to medical restrictions. Such factors can affect the child's ability to properly regulate its behavior. Secondly, the child's self-regulation can be influenced by disturbances in attention, which may occur independently of asthma or be associated with neuroendocrine processes. Regardless of its causes, they can hamper a child's ability to perceive asthma symptoms and respond to them in a coordinated fashion (McQuaid and colleagues, 2008). Some authors suggest that although several studies confirmed the safety of corticosteroid therapy (Pedersen, 2006), in patients with asthma and other allergies, more disturbances on the HPA axis were observed (Priftis and colleagues, 2008). It is possible that cortisol suppression not only increases inflammation, which makes asthma control more difficult, but also affects cognitive processes which are crucial for self-regulation (Annett and colleagues, 2005). In addition, asthma entails the risk of mild intermittent hypoxia associated with airway obturation. In children with congenital heart disease and sleep-distorted breathing such hypoxia is related to decreased IQ scores and symptoms of hyperactivity and impulsivity; however, there is no clear evidence of similar effects in asthma (Bass, Corwin and colleagues, 2004). A third explanation of the association between poorly controlled asthma and disturbances in attention and self-regulation is that they can co-occur with other environmental factors (e.g., low socioeconomic status, disturbances in the family system) which contribute to both the child's health and its psychosocial functioning (Goodwin and colleagues, 2004; McQuaid and colleagues, 2008). Because all these determinants are impossible to control in one research project, the results of existing and future studies should be interpreted with caution.

The role of executive functions in the self-regulation development

In the neurocognitive model proposed by M. Posner and M. Rothbart (2000), development of a child's self-regulatory skills is determined by one broad cognitive process: executive attention, defined as the ability to inhibit unwanted reactions and solve cognitive conflicts by interference control. Because recent studies indicate that children with poorly controlled asthma may exhibit difficulties both in cognitive tasks measuring attention and in behavioral control, as observed by their parents, it is possible that in these children executive functions may be distorted. The concepts "executive attention" and "executive functions" are often used interchangeably, depending on whether the authors consider them as either homogeneous or heterogeneous processes. Today, most researchers agree that executive functions are a collection of separate but interrelated cognitive processes responsible for the ability to control cognition and behavior, being situated in the prefrontal and parietal cortex (Collette, Van der Linden and colleagues, 2002; 2005). In the popular classification proposed by A. Miyakie, N. Friedman and colleagues (2000) three fundamental executive functions are distinguished: inhibition, shifting between tasks and working-memory updating. Reaction inhibition and interference control are usually seen as two types of inhibition (Nigg, 2000). Many authors include metacognition processes like planning, initiating, organization and monitoring of behavior in the executive functions classification (Gioia and colleagues, 2000; Best and colleagues, 2009). Authors of the article Behavior Rating Inventory of Executive Function (Gioia and colleagues, 2000) emphasize that the term *executive function* represents an umbrella construct that encompasses the abilities to initiate, plan, organize and sustain future-oriented problem-solving in working memory, as well as the ability to shift cognitive sets and modulate emotions and behavior via inhibitory control. There is general agreement that development of executive functions starts in preschool years, when both working memory span and the ability to solve cognitive conflicts increase (Posner, Rothbart, 2000). In older children, abilities develop to shift attention between tasks and to plan and monitor activities (Best and colleagues, 2009). It is known that disturbances in executive functions are related to children's impulsivity and social problems, whereas attention training reduces them (Rueda and colleagues, 2005; Berger and colleagues, 2007).

The aim of the study

The aim of current study was firstly to describe differences and similarities in various executive functions and self-regulation skills among children with asthma, their healthy peers and children with ADHD; and secondly to assess how illness variables influence children's executive functions and self-regulation. Four parameters of symptom control were used to assess significant illness variables. To our knowledge, executive functions were not yet directly investigated in children with asthma. It is then unclear whether asthma is associated with disturbances in executive functions and which of the self-regulatory skills can be particularly at risk when the illness symptoms are poorly controlled. As recent studies suggest that asthma may be associated with some symptoms of hyperactivity, impulsivity and inattention (McQuaid and colleagues, 2008; Yuksel and colleagues, 2008), we decided to include children with ADHD in the study. This enabled us to compare specificity and intensity of disturbances exhibited by children with ADHD and patients with poorly controlled asthma. Because disturbances in executive functions and self-regulation are considered as characteristic for ADHD (Barkley, 1997; Doyle, 2006) we assumed that they may be more severe in children with ADHD than in children with asthma. This assumption may not, however, be confirmed since the results of metaanalyses on executive functions in attention deficit/hyperactivity disorder (Doyle, 2006) emphasise that although children with ADHD usually have impaired inhibition performance and working memory, their neuropsychological profiles may significantly differ.

We hypothesized that

1. Children with asthma are less efficient in tasks measuring executive functions than their healthy peers, but they are more efficient than those with ADHD.

2. Children with asthma have more problems with self-regulation than their healthy peers, but less than those with ADHD.
3. Children with poor symptom control are less efficient in tasks measuring executive functions and have more problems with self-regulation but less than those with ADHD.

Method

Participants

One hundred and one children 8-11 years old (mean 9.48) and 101 parents participated in the study. The experimental group consisted of 30 children with asthma, all of whom were patients in a hospital's pulmonologic clinic. The control group consisted of 36 healthy peers, being students of three primary schools and similar to the experimental group in terms of demographic variables. The comparison group consisted of 35 children with ADHD combined type, all of whom were clients of psychological clinics and diagnosed by a child psychiatrist or neurologist. Patients diagnosed with any chronic diseases (other than asthma in the experimental group), allergies with breathing difficulties, intellectual disabilities or psychiatric disorders (with the exception of ADHD in the comparison group) were excluded from the study. Additional criteria for the experimental group were: at least two years since diagnosed with asthma and having minimal step II treatment, defined by the GINA Report (2006) as taking controller medications daily. Parents whose children met the inclusion criteria were invited to participate in the study by the experimenter in their clinic/school. Parents and children who decided to participate signed an agreement form after the study procedure was fully explained to them. All participants were Caucasian Polish. Remaining demographic characteristics of the groups are described in Table 1.

Measures

Four experimental computer tasks were created to assess executive functions in children: reaction inhibition, interference control, shifting between tasks and updating information in working memory. All tasks are modifications of the measures used in the adult population and their appearance and technical parameters were adapted to the abilities of 8-11 years old during a pilot study on 75 healthy children. Abstract images were replaced with color pictures to make the tasks more suitable for children. Each task was shortened to 60 pictures and the time needed for reaction was extended. After the pilot study no modifications of the

Table 1. Descriptive statistics of demographic variables

Group	Child's mean age	Child's gender	Residence	Parent's education	Number of children in the family
Children with asthma	9.5	F = 14 M = 16	City = 6 Small town = 9 Village = 15	University = 5 High school = 21 Vocational = 4	One = 5 Two = 13 Three = 12
Healthy children	9.38	F = 19 M = 17	City = 14 Small town = 10 Village = 12	University = 12 High school = 12 Vocational = 12	One = 2 Two = 16 Three = 18
Children with ADHD	9.57	F = 2 M = 33	City = 26 Small town = 7 Village = 2	University = 14 High school = 17 Vocational = 4	One = 11 Two = 18 Three = 6

measures were made. To assess children's self-regulation the BRIEF Inventory – Parent Version (Gioia and colleagues, 2000) and the modified BRIEF Inventory – Self-Report Version (Guy and colleagues, 2004) were used. Both versions, translated, were accepted by the publisher, Psychological Assessment Resources, Inc. The modified format of the BRIEF-SR cannot be used without written permission of PAR. The Asthma Control Test (Quality Metrics Inc., 2002) and medical protocol were used to assess illness variables. A full description of measures is presented below.

1. *Reaction inhibition task.* This is a modification of the "go/no-go" task (McVay, Kane, 2009). A child categorizes pictures of animals as wild or domestic and has to restrain himself from pressing a button when two indicated animals appear. The task consists of a training session (12 pictures with categorization only) and four series of a total of 60 pictures (half with wild animals, put in random order) preceded by instructions detailing which two animals the child shouldn't react to. The parameters of inhibition efficiency are the number of false alarms (pressing the button when "forbidden" animals appear) and medium latency time.

2. *Interference control task.* This is a modification of R. Navon's task (1997). Big letters (E, H, L or T) which are made of smaller ones appear successively on a screen. A child has to ignore big letters and recognize small ones by pressing the correct button. In the "consistent condition" big and small letters are the same, in the "interference condition" they are different. The task consists of a training section (12 letters) and a series of

60 letters (half in the "interference condition", put in random order). The parameters of inhibition efficiency are the number of incorrect reactions in the interference condition and medium latency time.

3. *Shifting task.* This is a modification of N. Meiran's (1996) and R. Rogers' and S. Monsell's (1995) tasks. Subjects had to categorize the pictures according to one of two dimensions, either as fruit or vegetable or as round or rectangular shape by pressing the correct button. An instruction which appeared every third picture gave information about the current valid dimension. Each picture could be categorized independently on both dimensions. The task consists of a training session (12 pictures) and a series of 60 pictures (half with the fruits and round shapes, put in random order). The parameters of shifting efficiency are the number of incorrect reactions and the medium latency time.
4. *Updating task.* This is a modification of G. Larson's and colleagues (1988) task. Pictures of a drink or a sandwich appear successively on a screen. A child has to count them separately and press the button when a bottle or sandwich appears for the third time. The task consists of a training session (12 pictures) and a series of 60 pictures (half with a drink, put in random order). The parameters of updating efficiency are the number of incorrect reactions and the medium latency time.
5. *Behavior Rating Inventory of Executive Function* (*BRIEF*, Gioia and colleagues, 2000) is a questionnaire for parents and teachers of 5-18 year olds created to measure behavioral manifestations of executive function in home and school environments. It contains 86 items within eight clinical scales: Inhibit, Shift, Emotional Control, and Working Memory (Behavioral Regulation Index); and Initiate, Plan/Organize, Organization of Materials, and Monitor (Metacognition Index). The test was adapted to the experimental version during a pilot study of 75 parents of healthy children. In the current study the test achieved high reliability scores ($\alpha = .74$-$.93$ for each scale, and $\alpha = .98$ for whole inventory).
6. *Modified Behavior Rating Inventory of Executive Function – Self-Report Version (BRIEF-SR)* (Guy and colleagues, 2004) is a shortened version of the original questionnaire, but adapted for 8-11 year olds. It contains half the items of the original version (40 items) within the same eight clinical scales: Inhibit, Shift, Emotional Control, and Working Memory (Behavioral Regulation Index); and Plan/Organize, Organization of Materials, Monitor, and Task Completion (Metacognition Index). The items from the

original version were chosen by a team of child clinical psychologists and based on a reliability analysis during a pilot study of 75 healthy children. After modification the test achieved high reliability scores (α=/67-.82 for each scale, and α = .95 for whole inventory).

7. *Asthma Control Test For Children 4-11 years old (ACT)* (Quality Metrics Inc. 2002) is a standard medical test measuring the quality of symptom control over the most recent four weeks. It contains eight questions (half for a parent and half for a child) about daily and nocturnal symptoms, limits to a child's activity, and the frequency in taking rapid-acting β-2 agonists.
8. *Medical Protocol* contains information from parents' interviews confirmed through a chart review about 1) the actual treatment stage according to the GINA Report (2006) defined by type and prescribed medicaments, 2) non-compliance (during the interview parents were asked by the experimenter how often they omitted administering medicaments to their children; parents could choose the answer: never / sometimes / often / we discontinued using medicines), and 3) number of acute asthma attacks during the illness. An acute asthma attack is defined as an exacerbation during which a child needs medical help or hospitalization instead of taking rapid-acting β-2 agonists at home.

Procedure

Each child and its parent met an experimenter once in a hospital ambulatory before medical consultation (experimental group) or in a school/psychological clinic (control and comparison group). Each meeting was conducted by a psychologist or a student trained in child clinical psychology, took place in a separate, quiet room and lasted about one hour. The child sat at a table with the experimenter and completed the tasks in the following order: 1) Reaction inhibition task; 2) Shifting task; 3) The BRIEF Inventory – Self-Report Version; 4) Interference control task; and 4) Updating task. Tasks measuring executive functions were completed by the child on a notebook. The administration of each computer task lasted five minutes and the administration of the BRIEF-SR Inventory – approximately 15 minutes. The BRIEF-SR was read to the child by the experimenter and the child selected answers with a pencil. A 10-minute break was provided when the experimenter saw the child was tired During the meeting the parent sat in the other part of the room so as not to disturb the child, and completed the BRIEF Inventory – Parent Version. At the end the parent participated in a short structured interview about asthma management and completed the Asthma Control Test together with the child. After three months, participants received a mailing with their results. They were not remunerated for participating in the study. The project got the approval of the ethical committee at the Jagiellonian University in Krakow.

Statistical approach

Analyses were performed with the program R (R Development Core Team, 2011). Each effect had a linear model fitted to it, with alpha of .05 (two-tailed). In order to obtain easily interpretable coefficients, all dependent variables were normalized, excluding reaction times (measured in milliseconds) as they already have a commonly understandable scale. *R* squared adjusted for the number of explanatory terms was reported. Analyses were divided into two groups. In all tests the child's health status was used as the only independent variable. Firstly we compared the efficiency of executive functions and self-regulation in children from the experimental and control groups. Three groups were compared in each model: healthy children, children with asthma and children with ADHD (a summary of estimated means is shown in Table 3 in the Appendix). Then we examined the connections between the executive functions, self-regulation and illness variables. Four groups were compared in each model: the control group, comparison group (similar to the first part) and two asthma groups divided according to a respective child's illness variable analyzed in every comparison/model (e.g.,. children with good and poor symptom control according to the Asthma Control Test for Children). Five factors which can put children's functioning at risk were identified: 1) poor symptom control in the last four weeks, 2) more intensive treatment, 3) the occurrence of acute asthma attacks, 4) non-compliance, and 5) early asthma onset. A full description of the illness variables is presented in Table 2.

Results

Executive functions. Children with asthma did not differ from healthy peers in executive functions efficiency, with one exception: they made more mistakes than healthy children in the shifting task ($F[2,99] = 10.19$, $R^2 = .15$, $B = .71$, $p = .005$) and made a similar number of mistakes compared to children with ADHD ($B = -.33$, $p = .17$). This indicates that children from the asthma group exhibit difficulties in sharing their attention between two tasks and flexibly switching between them. Compared to children with asthma, their peers with ADHD were less correct in inhibiting unwanted reactions ($F[2,99] = 4.48$, $R^2 = .064$, *B* = -.71, *p* = .006), controlling interfering stimuli (*F*[2,98] = 12.42, R^2 = .19, *B* = -1, *p* < .001) and updating information in working memory (*F*[2,99] = 5.69, R^2 = .085, *B* = -.69, *p* = .006). They were also slower than others at shifting between tasks (*F*[2,99] = 4.58, R^2 = .066, *B* = 109, *p* = .007).

Table 2. Numbers of subjects in each level of illness conditions

Variable	Condition	Description	Number of subjects
Symptoms control in last four weeks	Poor	< 20 points in Asthma Control Test	14
	Good	> 21 points in Asthma Control Test	16
Treatment intensity	Less intensive	II stage of treatment (GINA 2006)	19
	More Intensive	III stage of treatment (GINA 2006)	11
Acute asthma attacks	Yes	Presence of acute asthma attacks	16
	No	No acute asthma attacks	14
Compliance to treatment	Compliance	Child always takes medicines	14
	Non-compliance	Child sometimes does not take medicines	16

More differences were revealed when the impact of illness variables was examined. Children with good symptom control during the previous four weeks were more correct in inhibiting unwanted reactions (*F*[3,98] = 3.08, R^2 = .058, *B* = .8, *p* = .009) than children with ADHD, whereas children from other groups were similar to those with ADHD. Similarly, children with poor symptom control were slower that their peers with ADHD in shifting between two tasks (*F*[3,98] = 3.27, R^2 = .063, *B* = 135, *p* = .009).

Patients with more intensive treatment were slower at inhibiting unwanted reactions than those with less intensive treatment (*F*[3,98] = 4.66, R^2 = .098, *B* = 107, *p* = .002), children with ADHD (*B* = 116, *p* < .001) and even healthy peers (*B* = 90, *p* = .005). They were also slower than children with less intensive treatment at shifting between tasks ($F[3,98] = 5.14$, $R^2 = .11$, $B = 141$, $p = .018$) and controlling interfering stimuli ($F[3,97] = 3.46$, $R^2 = .069$, $B = 127$, $p = .015$). Patients with less intensive treatment were less correct than those with ADHD in reaction inhibition ($F[3,98] = 3.31$, $R^2 = .064$, $B = -.84$, $p = .004$), interference control ($F[3,97] = 9.03$, $R^2 = .19$, $B = -1.19$, $p < .001$) and updating ($F[3,98] = 4.06$, $R^2 = .084$, $B = -.81$, $p = .004$), while children with more intensive treatment were similar to their peers with ADHD. There was no speed-accuracy trade-off either in the inhibiting task or in the interference control task. In fact there was a positive correlation between speed and accuracy in both tasks (respectively: $r = .36$, $p = .046$, and $r = .48$, $p = .006$, $df = 29$).

Patients without acute asthma attacks were more correct in inhibiting unwanted reactions ($F[3,98] = 3.79$, $R^2 = .077$, $B = 1.1$, $p = .003$) and updating information in working memory ($F[3,98] = 4.34$, $R^2 = .09$, $B = 1$, $p = .005$) than children with ADHD, whereas others did not differ from them. Both children with acute asthma attacks ($F[3,98] = 6.96$, $R^2 = .15$, $B = -.61$, $p = .027$) and without the attacks ($B = -.9$, $p = .012$) were less correct than healthy peers in shifting between tasks.

Children who were taking medication strictly according to prescription were more correct in inhibiting unwanted reactions than children with ADHD ($F[3,98] = 4.36$, $R^2 = .09$, $B = 1.09$, $p < .001$). Compliant children were less correct than their healthy peers in shifting between tasks ($F[3,98] = 6.98$, $R^2 = .15$, $B = -.86$, $p = .007$).

Self-regulation. Parents of children with asthma reported generally more problems with their self-regulation than parents of healthy peers ($F[2,99] = 56.51$, $R^2 = .52$, $B = .45$, $p = .015$). However, they reported less problems in their children's everyday behavior than parents of children with ADHD ($B = -1.35$, $p < .001$). Comparing children's self-regulation profiles revealed that parents of children with asthma reported more difficulties in their emotional control ($F[2,99] = 21.41$, $R^2 = .29$, $B = .58$, $p = .008$), holding information in working memory ($F[2,99] = 32.95$, $R^2 = .39$, $B = .58$, $p = .004$), and initiating everyday activities ($F[2,99] = 30.35$, $R^2 = .37$, $B = .46$, $p = .024$) than parents of healthy peers. They did not differ from parents of healthy children in the assessment of such self-regulatory skills as: behavioral inhibition ($F[2,99] = 72.36$, $R^2 = .59$, $B = .2$, $p = .23$), switching between two activities ($F[2,99] = 26.7$, $R^2 = .34$, $B = .28$, $p = .18$), planning and organization ($F[2,99] = 33.4$, $R^2 = .39$, $B = .32$, $p = .1$), organization of material ($F[2,99] = 16.91$, $R^2 = .24$, $B = .21$, $p = .32$), and monitoring behavior ($F[2,99] = 34.2$, $R^2 = .4$, $B = .31$, $p = .11$). In self-reports children with asthma assessed their self-regulation similarly to their healthy peers ($F[2,99] = 12.48$, $R^2 = .19$, $B = -.07$, $p = .74$). Children with ADHD reported more difficulties with their everyday behavior than children and healthy peers (*B* = .95, $p < .001$).

All four illnesses variables moderated children's self-regulation. Parents of children with poor symptom control in the previous four weeks assessed their self-regulation worse than parents of the healthy group (*F*[2,98] = 38.61, R^2 = .53, *B* = -.65, *p* = .006). The same finding was observed in parents of children with more intensive treatment (*F*[2,98] = 39.22, R^2 = .53, *B* = -.74, *p* = .004). More difficulties in everyday behavior were reported by parents of children with acute asthma attacks compared to parents of those without attacks (*F*[2,98] = 40.86, R^2 = .54, *B* = .62, *p* = .003) and controls (*B* = .65, *p* = .002) as well as in non-compliant parents compared to compliant parents (*F*[2,98] = 40.79, R^2 = .58, *B* = .65, *p* = .029) and to those of the healthy group (*B* = .71, *p* = 0.001).

According to self-reports, children who were taking medication strictly according to prescription assessed their self-regulation better than non-compliant children (*F*[2,98] = 10.53, R^2 = .22, *B* = .73, *p* = .021), and those with ADHD (*B* = 1.35, $p < .001$). Other illnesses variables did not influence children's self-reports. These findings mean that compliance with prescribed medications may be particularly beneficial in terms of how children assess their self-regulatory skills.

Table 3. Estimated means and 95% confidence intervals (CI) of dependent variables for compared groups

Group	Lower 95% CI	Estimated mean	Upper 95% CI
Reaction inhibition task --- correctness, $F(2, 99) = 4.48$, $R^2 = .06$, $p = .01$			
Children with asthma	-.56	-.2	.17
Children with ADHD	.17	.51	.85
Healthy children	-.38	-.05	.29
Reaction inhibition task --- latencies, $F(2, 99) = 1.97$, $R^2 = .02$, $p = .15$			
Children with asthma	919	953	987
Children with ADHD	874	906	939
Healthy children	900	932	964
Shifting task --- correctness, $F(2, 99) = 10.19$, $R^2 = .15$, $p < .001$			
Children with asthma	-.06	.29	.64
Children with ADHD	.29	.63	.96
Healthy children	-.74	-.42	-.09

Shifting task --- latencies, $F(2, 99) = 4.58$, $R^2 = .07$, $p = .01$			
Children with asthma	881	938	995
Children with ADHD	775	829	883
Healthy children	869	922	975
Interference control task --- correctness, $F(2, 98) = 12.42$, $R^2 = .19$, $p < .001$			
Children with asthma	-.58	-.23	.12
Children with ADHD	.43	.77	1.1
Healthy children	-.61	-.29	.04
Interference control task --- latencies, $F(2, 98) = 2.0$, $R^2 = .02$ $p = .14$			
Children with asthma	1007	1057	1107
Children with ADHD	1079	1127	1175
Healthy children	1040	1087	1133
Updating task --- correctness, $F(2, 99) = 5.69$, $R^2 = .08$, $p < .001$			
Children with asthma	-.5	-.15	.2
Children with ADHD	.21	.54	.87
Healthy children	-.48	-.16	.17
Updating task --- latencies, $F(2, 99) = .54$, $R^2 = -.01$, $p = .58$			
Children with asthma	686	760	834
Children with ADHD	696	765	835
Healthy children	739	807	876
BRIEF Inventory – Self-Report Version, $F(2, 99) = 12.48$, $R^2 = .19$, $p < .001$			
Children with asthma	-.5	-.19	.12
Children with ADHD	.47	.76	1.06
Healthy children	-.41	-.12	.17
BRIEF Inventory – Parent Version, $F(2, 99) = 56.51$, $R^2 = .52$, $p < .001$			
Children with asthma	-.5	-.24	.03
Children with ADHD	.86	1.11	1.36
Healthy children	-.93	-.68	-.44

Discussion

According to the first hypothesis our study revealed that children with asthma generally exhibit more difficulties than their healthy peers in shifting attention between tasks, but less than children with ADHD. Since there are no similar differences in other executive functions -- reaction inhibition, interference control and updating -- the first hypothesis cannot be fully confirmed. Since it is considered that the shifting ability develops later than inhibition and updating (Best, and colleagues, 2009), further research is needed to determine whether difficulties in shifting are specific to children or whether they occur also in healthy peers and reflect regular child development.

According to illness variables, our study revealed that poorly controlled asthma is related to slight changes in reaction inhibition, interference control and updating; but none are as large as in the ADHD group. They manifest themselves primarily as a slowing down when faced with difficulties, and an increase in errors when the task is too hard for the child.

Although executive functions were not at that time being researched among the asthma suffering population, our findings accord with the studies of R. Annett and colleagues (2000) and E. McQuaid and colleagues (2008), where slight disturbances in children's attention were found. There are several reasons why executive functions may be susceptible to illness variables similarly to elementary cognitive processes. Firstly, for many children intensive asthma treatment occurs during preschool years when both attention and executive functions develop intensively (Best and colleagues, 2009) and thus it may affect children's development via neuroendocrinologically or psychosocially. Secondly, the development of attention and executive functions seems to be closely related (Posner, Rothbart, 2000). Finally, the tasks measuring executive functions engage many cognitive resources, including a child's attention (Fryt, Gacek, 2011). On the other hand our study reveals that changes in executive functions are associated with quality asthma control and shows a rather optimistic picture of patients' cognitive performances. Although more research is needed to determine how poorly controlled asthma may be a risk factor for children's executive functioning, our study, to our knowledge, is the first to investigate different executive functions in the asthma population.

According to the second hypothesis our study confirmed that parents of children observed more problems in their children's self-regulation than parents of healthy peers; however, these problems are not as large as in the ADHD group. Most children's difficulties are in the emotional control, working memory and initiating behavior domains, which accords with other authors' results suggesting that children's problems are mainly of an internalising nature (Goodwin and colleagues, 2004; Meuret and colleagues, 2006).

Although parents of children with asthma observe more problems in their behavior, the children themselves do not notice them, which is consistent with the M. Klinnert and E. McQuaid's findings (2001). It is noteworthy that discrepancies between parents' and children's reports are observed in the experimental but not in the ADHD group. There are several possible explanations for that finding, which can be considered in further studies. For example, difficulties that children with asthma have may be relatively small and do not affect their self-esteem. It is also possible that parents perceive their difficulties as part of the illness, and are less critical of their children than parents of children with ADHD.

According to the third hypothesis, our study revealed that most problems with self-regulation are observed by parents of those children with asthma whose symptoms are not properly controlled; where treatment is more intensive, acute attacks occur and patients sometimes do not receive the medicines prescribed by a doctor. According to self-reports, compliant children assess their self-regulation better than non-compliant children. These findings generally suggest that proper asthma management can protect children against the adverse effects of chronic illness (Fryt, Gacek, 2011). Although symptom control on children's behavior has been the subject of recent studies (Halterman and colleagues, 2006; Goldbeck and colleagues, 2007), further research is needed to determine which illness variables have a larger or smaller impact on children's self-regulation. Considering that parents, not their children are responsible for adherence to prescribed medications, it is interesting why compliance may be particularly beneficial in terms of how children assess their self-regulation.

There are several possible explanations for the disturbances in self-regulation in patients with less well-controlled asthma. According to neurocognitive self-regulation models, illness unpredictability and fear of acute attacks may cause a child's motivational defense system to become hypersensitive (Derrybery, Tucker, 2006) as well as create problems with directing attention volitionally (Posner, Rothbart, 2000). Another possible explanation is the subtle neuroendocrine changes associated with the asthma patomechanism, which may not cause significant cognitive deficits, but may instead influence more complex, executive and self-regulatory processes which develop intensively during preschool years (Fryt, Gacek, 2011). This hypothesis seems worth testing on the basis of recent advances in developmental neuropsychology (Berger and colleagues, 2007). It is also possible that the relation between poorly controlled asthma and disturbances in cognitive and behavioral functioning is not causal but results from confounding environmental factors threatening both the child's health and cognitive development (e.g., poverty, family problems, Goodwin, 2004; McQuaid and colleagues, 2008).

Our study has several limitations. Larger clinical groups are needed to confirm current results. Children with ADHD should be recruited more selectively to the comparison group in terms of demographic variables. The greater incidence of ADHD among boys and more parental education using psychological counseling are significant challenges in recruitment. Experimental tasks measuring executive functions should be fully adapted to allow comparisons with other measures of children's executive functions. Adherence to medical treatment should be monitored more precisely, using well-established self-reports, structured interviews or daily diaries (Quittner and colleagues, 2008). Doses of glicocortycosteroids and antileukotrienes should be controlled separately. To minimize the biases that may arise from conducting the study in a hospital, school and clinic, all participants should be examined in the same or similar environment. To identify major environmental factors that may affect asthma control and a child's self-regulation, the socioeconomic status or selected aspects of family functioning should be monitored. Future studies should designed to allow for separation of the psychosocial and neurocognitive factors that influence a child's functioning. There is also a need to investigate the long-term effects of asthma in longitudinal research.

Our study confirms the need for including psychological assistance in asthma treatment, especially with children who are at risk of behavioral disturbances. These are children whose asthma is poorly controlled, whose treatment is more intensive, and who have acute exacerbations and a history of non-compliance. In diagnosing cognitive functioning it is worth putting a greater emphasis on the assessment of children's attention and executive functions rather than their general intellectual ability. It is also important to notice disturbances in patients' self-regulation (increased anxiety, impulsivity, low tolerance to frustration, problems with social functioning and self-organization) as well as to identify psychosocial factors which perpetuate them (e.g. a family's inability to manage asthma symptoms and compliance to treatment). Individual training for patients (including stimulation of elementary and executive attention and metacognition skills) and parental counseling may be beneficial for that group. Attention training is confirmed to be an effective form of stimulation in children (Rueda and colleagues, 2005; Tang and Posner, 2009). In medical clinics counseling for parents may be concentrated on improving adherence. Providing written plans for asthma treatment and identifying individual barriers that prevent positive adherence may be a good first step toward improving a child's well-being.

Declaration of interest

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