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IS THE EXECUTIVE FUNCTION NECESSARY FOR INFERRING MENTAL STATES OF OTHER PEOPLE? EVIDENCE FROM STUDIES ON PATIENTS WITH BRAIN IMPAIRMENT[1].

Theory of mind (ToM) refers to the ability to represent the mental states of others. The Executive Function (EF) refers to higher-level cognitive processes encompassing planning, inhibition, coordination, shifting, and coordination of action sequences. Current studies on ToM and EF suggest that these two cognitive abilities might be functionally or anatomically linked. Although the relation between ToM and EF has been widely investigated, the results remain inconclusive particularly when considering the functional architecture of a mature brain system.

The present study aims to seek this lacuna with the use of neuropsychological methodology. The pattern of ToM and EF deficits within patients with brain injury were investigated. We compared the performance of four patients with a set of tasks examining theory of mind abilities and the Wisconsin Card Sorting Test (WCST) assessing EF functioning.

Results yielded a dissociation between ToM and EF, suggesting that in an adults' brain executive functions are not necessary for inferring the mental states of others.

Keywords: theory of mind, executive functions, brain impairment.

INTRODUCTION

Theory of mind (ToM) is the ability to represent mental states such as beliefs, intentions, and desires of other people (Baron-Cohen et al., 2000; Brune, Brune-Cohrs, 2006; Tirassa et al., 2006; Saxe, 2006). ToM is claimed to be vital for social intelligence development. The Executive Function (EF) is a term which refers to a higher-level action control encompassing planning, inhibition, shifting, and coordination of action sequences. These abilities are essential for maintaining mentally specified goals (Perner, Lang, 1999).

ToM has often been discussed as a single modular mechanism, but there is also a plethora of studies which focus on the role of cognitive skills such as executive functions (EF) in ToM processing. Existing studies have given rise to tthree possibilities: 1. ToM capacity might rely on executive functions abilities and there may be no domain-specific component designed to process information about mental states of others (Carlson, Moses, Claxton, 2004; Perner, Lang, 1999); 2. executive control does not play any role in adult mental state inferences; 3. executive functions facilitate ToM capacities but do not constitute them (Saxe, Schultz, Jiang, 2006).

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Authors supporting the first hypothesis attempt to show that theory of mind problems coincide with weak executive control (Carlson, Moses, Claxton, 2004). For instance, young children who fail on tasks requiring mental state inference also fail EF tasks (Zatichik, 1990, Roth, Leslie, 1998). Children are also more likely to pass theory of mind tasks when inhibition demands are reduced (Wellman, Bartsch, 1998). Moreover, performance on ToM tests correlates with EF abilities (Carlson, Moses, Claxton, 2004; Perner, Lang, 1999). On the basis of the aforementioned results, researchers suggest that a dysfunction or underdevelopment of EF will result in the inability to understand mental states of other people, as in order to understand false beliefs of others' one has to inhibit one's own true beliefs. Consequently, change in the ability to reason about others' mental states at the age of four may reflect executive control development, not an alleged shift in ToM processing.

Still, many investigations into ToM mechanisms underpin the abovementioned account, arguing that no study has directly demonstrated that theory of mind ability may be fully explained by EF. For example, although Chinese preschoolers out-perform American children on EF tasks their performance on ToM tests is comparable with American peers (Sabbagh et al., 2006). EF and ToM abilities may also show different patterns of dysfunction among children with autism. Autistic children have problems with false beliefs tasks but perform well on control tasks (i.e. ones which differ in mental states understanding requirements), though have comparable executive control and inhibition demands to healthy children (Leslie, Thaiss, 1992). Still, it is difficult to investigate the architecture of cognitive systems if researchers only focus on young children.

Recent studies have revealed that the nature of the relation between ToM and EF may be more adequately examined by complementing developmental studies with research on adults (Apperly, Humphreys, Samson, 2009). The link between performance on ToM and EF tasks in studies on children does not necessarily reflect an intrinsic relation between the aforementioned cognitive processes. Researchers noted that EF may play an important role in ToM emergence during childhood, but mature theory of mind ability might not rely on executive functions (Saxe, Schultz, Jiang, 2006).

Three independent lines of research conducted on adults suggest that the relation between EF and ToM may be less clear than previously stated on the basis of studies performed on children.

First, the growing interest in fMRI research on the neural basis of TOM and EF has enabled the indication of multiple brain components implicated in these complex cognitive processes. Depending on tasks used to elicit EF, distinct brain structures were identified to be associated with different aspects of executive functions: anterior cingulated cortex (ACC), dorsalateral prefrontal cortex, superior parietal lobule, ventrolateral prefrontal cortex, orbitofrontal cortex, medial frontal areas (Ardila, 2008), bilateral frontal eye fields, intraparietal sulcus, and frontal operculum (Culham, Cavanagh, Kanwisher, 2001). ToM tasks (usually false belief tasks) were reported to activate a set of brain regions including the temporoparietal junction, medial prefrontal cortex, posterior cingulated cortex, and amygdala (Abu-Akel, 2003; Gallagher et al., 2000; Saxe, 2006). Identifying neural correlates of the aforementioned processes provides interesting results but is only the first step in helping to understand the nature of the relation between different components of EF and ToM. In order to answer the question to what extent ToM relies on EF in an adult's brain, it seems crucial to investigate ToM and EF in the same experiment as opposed to separately. Saxe and colleagues (2006) have identified both separated and overlapping brain structures involved in ToM and EF, suggesting that both domain-general and domain specific cognitive processes are implicated in ToM in adults (Saxe, Schultz, Jiang, 2006).

The presented results are in line with a growing body of research yielding that although ToM tasks engage some aspects of EF, creating representations of the mental states of other people relies on domain-specific brain mechanisms (Saxe et al., 2006). Recently, fMRI studies have started to be complemented with neuropsychological research on patients with brain lesions. For instance, Bach and colleagues (2000) have presented patients with dissociation between EF and ToM. In line with this result, Havet-Thomassin and colleagues (2006) reported a lack of correlation between ToM and EF. Nevertheless, some authors claim that the patients' failures in ToM tasks might result from EF impairment (Henry et al., 2006). Inconclusive results in this respect may reflect the nature of higher order cognitive processes such as ToM ability, which may be mediated by multiple, interactive brain networks. It seems crucial to better elucidate the cognitive mechanisms underlying the ability to reason about the mental states of others. Although existing fMRI studies may help to reveal brain structures involved in realizing particular mental processes, they cannot determine whether specific brain areas serve as a core system inevitably engaged in a specific domain of cognition. By contrast, research on patients with brain lesions may provide evidence that two cognitive systems function separately by depicting dissociation within examined cognitive domains (Havet-Thomassin et al., 2006).

Existing lesion studies have yielded important outcomes but due to contradictory results, different protocols, and small groups sizes the conclusions are limited and need further examination.

The present study aims to investigate the relation between ability to infer mental states of others and executive functions within patients with brain lesions. In order to depict different patterns of deficits in the studied cognitive domains (EF and ToM), methods of clinical neuropsychology (case studies) were applied.

The aim of presenting the performance of four patients reflects a classical methodology of clinical neuropsychology, in which a case studies approach is considered to make a significant contribution to better understanding of the human cognition architecture. Case studies are in particular employed to show double dissociation of neuropsychological functions. It is suggested that double dissociation occurs "when patient A performs task I significantly better than task II, but for patient B, the situation is reversed . . ." (Shallice, 1988).

Contrary to many others studies, we decided to examine theory of mind ability with the use of more elaborated tasks than previous authors. Such an approach allowed us to test the understanding of not only false beliefs tasks but also more complex social interactions requiring inference of mental states.

METHOD

ToM tasks

To investigate the theory of mind, a set of 18 short stories referring to characters' mental states was designed based on available tasks in the literature (e.g. Shamay-Tsoory et al., 2007) and original tasks developed by the authors. In order to examine an understanding of a wide range of social interactions, the stories depicted:

1) false belief (tasks examining the ability to understand that someone else's behaviour may result from a belief which is false);

false attribution (tasks examining the ability to understand that relying on the physical appearance of person A may misinterpret the mental state of person B, e.g. A thinks that B is sad because A sees tears, when the tears are in fact the result of cutting an onion and not being upset);

lie (tasks examining the ability to understand the motives underlying lying e.g. manipulation, a white lie, etc.) ;

irony (tasks investigating the ability to indicate and understand irony and its motives);

faux-pas (tasks investigating the ability to indicate faux pas and its consequences).

After being presented each story, patients were asked two kinds of questions: A) mental questions, and B) control questions. In order to correctly answer mental questions a subject had to understand the state of the mind (beliefs, intentions, emotions) of the characters in the stories. Control questions could be answered correctly without mental state inference. They served as a measure of understanding the literal meaning of the story and examined whether the subject remembered the storyline.

The scoring system enables a more detailed characterization of ToM impairment and distinguishes between several kinds of answers:

- 2 points - full answer with mental state inference;

1 point - a partial answer;

0 points – the lack of or incorrect answer

Patients who had more than 50% errors on control questions and were reported to have problems with understanding speech were excluded from the study. During the initial stage of the study, a group of healthy adults were examined to define an „answer pool".

Executive functions assessment

To evaluate executive functioning the Wisconsin Card Sorting Test (WCST) was administered. It enables the determination of a wide range of cognitive processes involving mental flexibility, inhibition, and abstract reasoning (Greve et.al., 1997). Standard protocol was used during the neuropsychological assessment. According to the test guideline, the following indicators were assessed: Total errors, Percentage of conceptual level responses, Categories completed, Perseverative errors, and Perseverative responses.

Participants

The presented study focused on 4 out of the 58 patients with brain lesion reported in Pluta (2011, unpublished Ph.D. dissertation).

In the presented study, we employed one of the most common case studies approaches, in which a patient's performance is compared to a matched control sample. In order to refer individual patient data to the control group, patients' performance was converted into z-scores (Crawford, Howell, 1998).

The patients had lesions to the frontal lobe, subcortical structures, and temporal lobe. Site of the lesions was confirmed by computer tomography (CT) or magnetic resonance imaging (MRI). The clinical characteristic of the patients are presented in Table 1.

The patients' results were compared to those of a control group. The control group consisted of 22 healthy controls matched to patients (58 subjects with brain lesions examined in Ph.D. project) for age, educational level, and gender. All participants were native Polish speakers. None of the subjects had a history of drug or alcohol abuse, nor a history of neurological or psychiatric diseases prior to the examination. All subjects gave their informed consent prior to the study.

Statistical analysis

During statistical analysis, we applied a common neuropsychology procedure in which the performance of a particular patient is compared to that of a control sample (Crawford, Garthwaite, 2002). In order to form inferences about the profile of patients' cognitive functioning, their raw data was standardized based on the control group's scores (mean and standard deviation). Then, we reduced the number of variables with the use of principal component analysis (PCA). The goal of this procedure was two-fold: 1. comparing relative values of several different variables which originally had different units of measurements for a case, and 2. referring

Table 1. Patients' characteristic and lesion description.

	AB	BR	PJ	DK
Gender, age, hand-ness	M, 29,R	M, 61, R	M, 63, R	F, 45, R
Main lesion site	Prefrontal cortex bila-terally, temporal lobe in RH	Subcortical structu-res of LH	Subcortical structu-res of LH	Ventral part of frontal lobe of RH
Aetiology	TBI	stroke	stroke	stroke
Major clinical symptoms	Speech slowdown	Speech slowdown	Speech slowdown	unpredictable and unacceptable beha-viour (e.g. stealing objects, compulsive eating), loss of exe-cutive control, disin-hibition, compulsive behaviours

Legend: R - right handed; RH – right hemisphere, LH – left hemisphere, TBI – traumatic brain injury.

Table 2. Rotated (Varimax) Factor Structure for the Chosen Sample.

Factor	Test	WCST measurement	Factor load
General executive fun-ctioning	WCST	Total errors Perseverative answers Percent of conceptual level responses Perseverative errors Categories completed	.931 .921 -.917 .907 -.791

an individual patient's performance to healthy control's outcomes.

In order to reduce the number of variables, a principal component analysis was undertaken on WCST scores gained by 58 patients. Five WCST scores were submitted to PCA with a varimax rotation: Total errors, Percentage of Conceptual level responses, Categories completed, Perseverative errors, and Perseverative responses. The PCA results are presented in Table 2.

The PCA conducted on the aforementioned scores resulted in a one-factor solution. Construct validity of this factor involved all examined measurements from WCST, so it was assumed that the factor score reflects general executive functioning (see Greve et al., 1997).

A new EF factor was created on the basis of the following equation:

General executive functioning score = [-(Total errors+ Perseverative answers- Percentage of Conceptual level responses+ Perseverative errors- Categories completed])/5

In order to investigate the null hypothesis that patients did not differ in neuropsychological per-

Table 3. Patients' performance on ToM and EF tasks.

Neuropsychological assessment	AB	DK	PJ	BR	Control group X (SD)
ToM	78	74	49*	37*	80.6 (6)
ToM control	36	36	32*	30*	35.5 (0.9)
Standardized score	-0.33	-1	-5.17*	-7*	0 (1)
WCST					
Total errors	67*	73*	50	46	26.4 (19)
Perseverative errors	10	66*	30	25	14.3 (11.6)
Perseverative answers	10	93*	33	71*	16.4 (14.2)
Categories completed	2*	1*	5	5	5.5 (1)
Percent of conceptual level responses	36*	16*	55	55	66.6 (17)
General executive functioning (standardized score)	-1.33	-3.94*	-1	-0.75	0 (1)

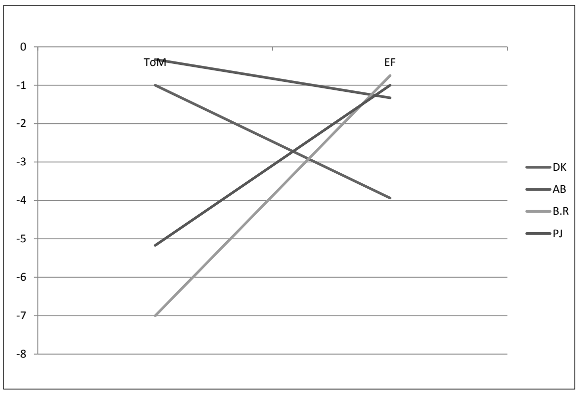
Legend: X – mean; SD- standard deviation, * Significantly less than controls ($p < 0.05$)

formance from the control group, we employed the procedure of Crawford and Garthwaite (2002) for comparing a single case with a control population. All computations were conducted in Singlim.exe (www.abdn.ac.uk/~psy086/dept/psychom.htm#singslope) which implements statistical methods developed in the paper mentioned above.

RESULTS

After initial stages of statistical analysis which enabled us to prepare raw data for further examination, we first compared the four patients' outcomes with those of the control group and then elucidated different patterns of deficits within ToM and EF with the use of Singlim.exe. The four patients' results are presented in Table 3.

The aforementioned results reveal different patterns of deficits in ToM and EF among the four patients. Patients AB and DK have no problems with inferring mental states but demonstrate an EF dysfunction (in the case of AB, EF dysfunction is reflected by a significant difference in total errors, categories completed, and percent of conceptual responses), while patients PJ and BR manifest the opposite neuropsychological profile: intact EF and significant ToM impairment. Presented outcomes suggest dissociation between the ability to reason about mental states and executive functioning, and might be better illustrated by Graph 1.



Graph 1. Patients' performance in ToM and EF examination (total score).

In order to better understand the nature of patients' problems with ToM and EF, we also investigated their performance separately.

Patient BR

A statistical analysis comparing BR's responses with those of the controls revealed significant differences in the following tasks: TOM [t = -7.107, p<0.001]; ToM controls t = -5.977, p<0.001, perseverative answers [t = 3.761, p<0.001].

Quantitative analysis of BR's answers in ToM tasks revealed profound difficulties with inferring mental states of other people. BR's answers were often incorrect or imprecise. Although BR knew that characters' behaviours were preceded by particular beliefs, emotions, and intentions, he was not able to indicate them correctly.

His answer after the presentation of story two is an example of this deficit (see Appendix). To the question "How did the husband feel when he saw the wife crying?*"* he responded: "He spotted that she is crying. He feels something. Does he feel perplexed?*"*

In story three (see Appendix), when asked "Why did the mum say that?*"* he answered: "A tricky question… I don't know. What kind of wife is she? Normally, you have to be mad. Maybe she was madly in love.*"*

The patient did not have problems with control questions, which confirmed a preserved ability to understand the literal meaning of the story. BR could also effectively retrieve information from memory. Considering the lack of an executive dysfunction, difficulties with ToM tasks could not be explained by declined abstract reasoning (Patient indicated 5 out of 6 rules in WCST), mental inflexibility, or executive control problems.

Patient AB

AB's performance in ToM examination revealed an opposite pattern of deficit in comparison to patients BR and JP: a relatively intact ability to infer mental states of others and an executive dysfunction. In particular, very low outcomes within Categories completed (AB indicated only two categories: colour and shape. Even after showing the category „number" he had problems with understanding the rule) yielded that AB has difficulties with abstract reasoning. On the basis of a relatively small number of perseverative errors, it might be assumed that in this case bad performance in WCST does not result from mental inflexibility, but rather from limited abstract reasoning ability. The statistical analysis comparing AB's responses with those of the controls revealed significant differences in the following tasks: Total answers [t=2.193, p<0.05], Categories completed [t=-3.423, p<0.05], and Percent of conceptual level responses [t=-1.76, p<0.05].

In sum, AB shows an executive dysfunction limited to severe abstract reasoning problems but no ToM impairment.

Patient DK

Patient DK showed a similar pattern of cognitive functioning to AB: significant executive dysfunction and intact ToM reasoning. The statistical analysis, comparing BR's responses with those of the controls revealed significant differences only in the following tasks: Total errors [t = 2.39, p<0.05]; perseverative errors [t = 4.35, p<0.05 perseverative answers [t = 5.27, p<0.05]; number of categories t =2.9 p<0.05]; Percent of Conceptual level responses [t = -2.9, p<0.05].

Her problems were especially manifested by disinhibition. Interestingly, when she was presented with the cards and WCST instructions she spontaneously spotted that the cards might be correctly sorted according to colour, shape, and number of elements. However, during neuropsychological assessment she was not able to apply this knowledge and committed multiple persevaretive errors. Nevertheless, her ability to infer mental states was relatively intact proving that self-control is not essential to understand the intentions, beliefs, and emotions of other people.

Patient PJ

PJ's performance on EF and ToM tasks also revealed dissociation between these two cognitive domains. Although he had significant problems with mental state inferences (ToM [t = -5.15, $p<0.001$]; ToM controls [t = -3.8, $p<0.05$]), EF functioning was relatively intact ($p>0.05$).

A detailed analysis of the patient's answers in ToM assessment yielded that PJ knew that other people have mental states which might differ from his own and reality, but was usually imprecise when indicating the intentions underlying certain behaviours. Significant problems occurred especially when he attempted to explain complex social interactions involving irony, lie, and faux pas. This pattern of deficit is consistent with developmental studies showing that the ability to understand complex mental states, which is acquired during development at the latest stage, is most vulnerable to impairment by brain lesion. This rule could be perceived in the following ToM tasks.

In story three (see Appendix), when asked "Why did the mum say that?" he answered, "She said that with love."

In story four (see Appendix), when asked "Why did Kate say that" he answered, "Because her hairdressing was very nice."

DISCUSSION

The current study is the first in Poland and one of the few in the world which presents the dissociation between theory of mind abilities and executive functions with the use of neuropsychological methods.

Our data shows that the executive dysfunction alone cannot account for theory of mind deficits. Due to small sample size, the results of this research should be treated with caution; however, they clearly suggest that ability to infer mental states of others cannot be reduced to executive functions. These findings are in line with many authors arguing that ability to infer mental states of others involves a domain-specific cognitive module (e.g., Saxe, Kanwisher, 2003).

One explanation of our results might be that in the mature functional architecture of the theory of mind, executive functions are no longer essential to sustain ToM. The aforementioned conclusion is consistent with other studies on adults (Apperly et al., 2004; Samson et al., 2004). For example, Apperly and colleagues (2004) reported three patients who manifested significant ToM problems even when inhibitory demands of the ToM task were reduced, and patient WBA who presented the reverse pattern of dysfunction (no ToM impairment when EF demands were minimized).

The presented study provides new evidence for a dissociation between EF and ToM, but a methodological concern should be pinpointed. It is related to different localization of lesions and aetiology. Although it might have affected the results, it did not reduce its clinical and cognitive value. Clinicians should be aware that theory of mind impairments might result from brain injury and do not necessarily co-occur with EF dysfunction. ToM impairment may significantly affect patients' lives and make social functioning difficult to attend or even understand. This information is particularly important for patients' families, caregivers, and clinicians because it implicates a change in everyday interactions. For instance, during everyday conversation caregivers should avoid non-direct communications such as irony because they might be misunderstood by patients. We should also comment on differences between patients' ages. Recent research has found that aging affects EF but not ability to represent mental states of others (German, Hehman, 2006). Problems with ToM observed in older subjects result from high executive control demands and not the inability to understand mental states of others itself. In the presented study, the oldest patients BR and PJ did not have EF impairment so severe that ToM impairment was related to the brain injury.

Interestingly, the presented results did not support studies which suggest that mainly the right hemisphere and prefrontal cortex are involved in mentalization. Quite contrary, two patients whose injury affected the prefrontal cortex in the right hemisphere did not show ToM problems, but ToM dysfunction was present within patients with subcortical lesion to the left hemisphere. However, our results are convergent with Birdh et al. (2004) who showed that patient G.T. suffered from dysexecutive syndrome resulting from a bilateral ACA infarction. EF problems in the aforementioned case were not accompanied by ToM impairment. This study showed that ToM impairment does not always follow medial frontal damage. Moreover, the current neuroimaging results suggest that frontal activity observed during fMRI studies on ToM is related to some involvement of executive control which is necessary during response selection. However, the ability to construct representations of mental states of others relies on independent neural substrates (Saxe, Schultz, Jiang, 2006). Furthermore, in the presented case studies we did not aim to identify the precise relation between the localization of the lesion and patterns of cognitive functioning. For that reason, further fMRI research and patient studies on large homogeneous groups are needed (Muller et al., 2010).

In summary, this study provides further support for a dissociation between ToM and executive functions in adults.

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APPENDIX

Examples of the stories used in the present study.

False belief

1. A sister and a brother sit in a children-room and pack a birthday present for their mother. When the present is packed, they hide it under the bed so that mother does not find it before the birthday party. The sister leaves the room and goes to the garden to pick flowers for mother. In the meantime, the brother moves the present to the wardrobe. The children agreed that the sister will hand over the present and the brother will give flowers to mother. The sister is going to the room to bring the present…

1. Where will a sister look for the present?

Where, according to the brother, is the sister going to search for the present?

Where is the present?

What were children doing?

<u>False attribution</u>

2. A wife is cutting an onion. The spice smell of the onion makes her cry. Tears started to drop from her eyes. She decides to have a short break and she goes to talk with her husband. The husband looks at the wife and asks "Darling, why are you miserable? Has something wrong happened?"

1.What does the husband feel when he spots the wife?

Why does the husband think that the wife is miserable?

How does the wife feel?

What was the wife doing?

<u>Irony</u>

3. A wife is coming back from holidays and she perceives that during her absence her husband didn't clean the flat once. The wife is looking around a room, which is extremely untidy, and she says: *Darling, how lucky I am, that I have married a man that is so inclined to keep the home in tidy conditions.*

1.Why did the wife say that?

What did the wife feel?

How, according to wife, should the husband feel?

Was the room tidy?

Where did the wife go?

4. Two friends, Barbara and Kate, are talking during the party. They spotted Helana, who they dislike. Helena was at a hairdresser, but unfortunately the hairdresser has chosen improper hairdressing and Helena looks awful. The two friend smile knowingly, and Kate says: „*Helena is a wonderful hairdresser. Eventually she will find her style*"

1.Why did Kate say that?

Did the two friends think that Helena has a pretty hairdressing?

Does Barbara think that Kate likes Helena's hairdressing?

Does Helena have a nice hairdressing?

Where were the friends?

<u>Lie</u>

5. Pieter made an appointment with Margaret. He finds her very attractive and he is desperate to impress her. The couple meet in Kate's favourite stud. She rides horses very well. Peter didn't reveal that he can't ride a horse and he prefers to avoid it. Kate is sitting confidently on a horse's back and she is encouraging Pieter to follow her. Suddenly Pieter, who is a great actor, puts his hand on his chest and murmured: „My heart, my heart hurts me so much"

1. Why did Pieter say that?

2. What does, according to Pieter, Kate think about his behavior?

3. Did Pieter really have heart pain?
4. Where did the couple meet?

Faux Pas

6. Two friends, Marta and Anna, meet at a party. „I can see that pregnancy serves you well. It should be the fifth month, isn't it?", says Marta, looking at Anna's rounded belly. „But I am not pregnant"- says Anna.

1. Did anyone say something improper?
2. Why did Marta congratulate her friend?
3. How did Anna feel when she heard congratulations?
4. Is Anna pregnant?
5. Where were the friends?