Maastricht Student Journal of Psychology and Neuroscience (MSJPN)

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# Maastricht Student Journal of Psychology and Neuroscience

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*(eds.)*

Maastricht University

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# LETTER FROM THE EDITORIAL BOARD

Dear reader,

We are extremely pleased to present you the first edition of the Maastricht Student Journal of Psychology and Neuroscience (MSJPN). The idea to initiate a student journal for the Faculty of Psychology and Neuroscience dates back to 2009, and is inspired by the Maastricht Journal of Liberal Arts from University College Maastricht. Although students of our Faculty of Psychology and Neuroscience have an academic writing assignment in each curriculum year, it was noted that actual scientific output by Bachelor students was scarce. In addition it appeared that, due to governmental decisions concerning academic performance, a majority of the students were strictly focusing on their mandatory courses and related educational results. Academic creativity and general academic development seemed to become underexposed. Therefore, the journal's main goal is to stimulate students in their academic development and to create a platform for students to publish both empirical and literature research. MSJPN is supposed to provide an annual reflection of student's activities in scientific research at the Faculty of Psychology and Neuroscience of Maastricht University. Students are offered the possibility to publish original research articles deriving from, for instance, studies conducted during their second year practical research course. Other articles can for example be a literature review based on the third year's Bachelor thesis. Obviously, the editorial board very much appreciates other types of scientific output arising from personal scientific reflections as well.

This first edition of MSJPN proofs that students at our faculty are still highly motivated to do more than only conventional curricular activities during their education. (Research) Master students were provided with the opportunity to play a role in the review process, increasing the student's involvement in this journal. The students did an excellent job by providing expert feedback to the authors and consequently improving the quality of the papers.

The editorial board would like to show its gratitude to all contributors of the journal. First of all, we thank the authors for submitting their scientific contemplations. We have enjoyed reading the papers and were immensely glad to see that there are students who are willing to distinguish themselves. Many thanks as well to our reviewers for reading all papers and for providing strict, but fair comments. We would also want to thank the faculty board for supporting us in realizing this journal. A special thanks to Marcel Schrijnemaekers for assisting us in all advertorial, financial and publisher activities. And lastly, we would like to thank Joris van Veghel for the design of the journal.

We hope that this first edition of the Maastricht Student Journal of Psychology and Neuroscience will be the start of a long lasting tradition and that the journal will soon become a household name within the Faculty of Psychology and Neuroscience of Maastricht University.

The editiorial board: Anke Sambeth, Silke Conen, Tim Leufkens

LAURA BORGHANS & MYRTHE PRINCEN

# The stability of memory performance using an adapted version of the Delayed Matching To Sample task: an ERP study

ORIGINAL PAPER

This study examined the stability of performance using an adapted version of the Delayed Matching to Sample memory test (DMTS). With this test the stability of visual working memory can be measured. In the DMTS participants have to memorize a cue for a certain delay, after which a probe is presented. This is an often used test, but it is not yet clear if the performance of this test is also stable over time. In present paradigm stability was assessed mixing short (10-20s) and long delays (140-200s) and presenting cues during the cue-probe interval. Additionally, EEG was measured during testing. For the memory-related components, the P300 and P600, amplitude and latency were compared between sessions and the same was done for accuracy and mean reaction time of behavioral data. Faster reaction times for long delay stimuli were found in Session 2. No effects in accuracy were found. Longer P600 latencies were found for long delay stimuli in the first session as compared to the second. High correlations between sessions were found for almost all other measures. These high correlations suggest that test-retest scores were stable. Therefore, we conclude that the new DMTS paradigm has high stability.

**Keywords:** Delayed Matching to Sample; ERP; memory stability, EEG

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## INTRODUCTION

The DMTS is a computerized test that has frequently been used to assess visual working memory in a variety of settings, such as in animal (see Dudchenko, 2004, for review), clinical (e.g., Chamberlain et al., 2011), and pharmacological studies (e.g., Turner et al., 2003). In the DMTS, participants hold an item (the cue) in memory for a certain delay, after which they receive a probe and have to choose the remembered item amongst a number of distractor items. In the typical DMTS, for instance the one developed by Cambridge Cognition (i.e. the CANTAB, see also Turner et al., 2003), the cue-probe interval usually varies from 0-12 s (Chamberlain et al., 2011; Turner et al., 2003). By possibly varying the delay periods, it makes the test perfectly suitable to investigate the various memory storage phases, i.e. encoding and consolidation. In this study, the stability of memory in an extensively modified DMTS was examined in order to establish whether repeated testing makes sense using this paradigm.

For intact learning and comprehension, working memory is needed. Baddeley (2003) proposed a model of working memory, which consists of the phonological loop, the visuo-spatial sketchpad and the episodic buffer. These components are supervised by the central executive that directs attention to relevant information. The visuo-spatial sketchpad is assumed to hold visual and spatial information. Because the visuo-spatial sketchpad is engaged when performing visual tasks we were particularly interested in this aspect. Here we used a DMTS with two intervals, namely 10-20 and 140-200 s, mixing the trials with short and long delays. The 10-20 interval represents memory encoding and this interval is used often in studying the DMTS. In our paradigm a new interval was additionally presented. This 140-200 s was used to examine the stage of memory consolidation. Evidence from animal studies suggests that the longer the interval, the less the accuracy (Grant, 1991). Also in humans an impaired accuracy was found in a visual array task, in which longer delays resulted in lower accuracy regardless of cognitive load (Ricker, 2010). This would suggest that in the present paradigm the performance of the participants should be decreased when the delay is longer. However, due to another modification, namely presenting 2 probe items instead of 4, the general load of the test was decreased to some extent, making the load more equal to standard DTMS tasks. Typically, no other stimuli are presented during the intervals between a cue and a probe. Here, however, cues were presented during the cue-probe intervals. This could reduce the test by around 15 minutes. To conclude, a strongly modified version of the DMTS was used in this study.

In a new paradigm, it is important to assess the stability of responding, i.e., whether scores are similar on various test days. Examining this issue was the main aim of this study, especially since stability has, to our knowledge, not critically been evaluated so far regarding the DMTS, especially not in a modified version as used here.

Electroencephalography (EEG) is a method to measure electrical brain activity. Electrodes placed on the scalp can record small changes in overall electrical activity in response to a stimulus. Averaging the responses evoked by a stimulus, an event related potential (ERP) containing various components can be extracted, which is caused by and time locked to sensory, motor or cognitive processes (Luck, 2005).

ERP components can be described by polarity and order of occurrence by extracting amplitude and latency. In this study, ERPs were recorded in response to the probes, because performance for encoding (i.e., short delay stimuli) and consolidation (i.e., long delay stimuli) can be assessed by looking at the accuracy of responding to probes.

ERP components of interest in this research were the P300 and P600. The human P300 component is a positive wave, elicited approximately 300 ms after stimulus onset. It is affected for example by stimulus probability, attention and expectancy (Kaestner & Polich, 2011), but is also enlarged for memorized compared to unfamiliar items (Mecklinger, 2010). Previous research has shown high test-retest reliability, thus stability, for the amplitude and latency of the P300 (Hall, Schulze, Rijsdijk, Picchioni, Ettinger et al., 2006). A P600 component also has a positive amplitude with a peak approximately 600 ms after stimulus presentation. The P600 is specifically related to memory processes (Mecklinger, 2010) and generally increased during memorization of the cue in a DMTS (Klaver et al., 1999.

The aim of this research was to investigate whether visual working memory, measured using a novel version of the DMTS, is stable over time. The stability of performance was established over two sessions by comparing accuracy and mean reaction time for behavioral data, and peak latency and amplitude for the P300 and P600 components. Klein and Fiss (1999) also found high stability for working memory. Therefore, behavioral data (accuracy and reaction time) as well as the ERP components (latency and amplitude) were expected to be equal in both sessions. Additionally, stability for short vs. long delay stimuli would be equally strong. In other words, the stability was expected to be very high for all dependent variables. Finally, it was expected that performance for longer delays would be slightly decreased compared to shorter delays, meaning less items would be remembered for longer delays.

## METHODS

### Participants

The participants were 20 right-handed students of Maastricht University (17 female), recruited via advertisements at university. The participants' mean age was 20.55 (range 18-27). The study was approved by the ethical committee (Ethische Commissie Psychologie) at Maastricht University and participants signed an informed consent before participation. They were rewarded with 5.5 course credits.

### Design

In this study a within subject design was used, with session as within subject factor. The dependent variables were: reaction time (ms), accuracy (%), peak latency (ms) and peak amplitude (μV). To make sure that different versions of the task would not have influence on the participants' performance, two different versions of the test were balanced over participants. In these versions, only the pictures were different.

### Procedure

The participants had to come to the lab three times, once for a training session and twice for a test session. The purpose of the first session was to train the participants to become familiarized with the tests. During this session no EEG was recorded. The training session had a duration of 1 hour. The first and the second test session were the experimental sessions, in which EEG was recorded. These sessions had a duration of 1.5 hour each. These sessions were at the same time of the day, but with a delay of one week. In this way, for each participant the stability over the same amount of time was assessed, possibly reducing variance between participants.

### Measuring EEG

An EEG cap was used to place a set of 32 EEG electrodes according to the international 10-20 system (Jasper, 1958). A reference and a ground was placed at the linked mastoids and at the forehead, respectively. Eye movements were detected by horizontal and vertical electro-oculogram (EOG) recordings. Before electrode attachment, the positions were slightly scrubbed with a gel in order to provide good conductance. The impedance value was <10 kOhm. Both EEG and EOG were filtered between 0.01 and 100 Hz and sampled at 500 Hz.

### DMTS

The test consisted of 50 immediate (interval between encoding and recognition 10-20 s) and 50 delayed (interval between encoding and recognition 140-200 s) recognition trials. Pictures were presented one by one in the middle of the screen. These pictures were mixed with 100 recognition trials, which consisted of the presentation of a new picture and an old picture, presented together in the middle of the screen. There were 50 recognition trials, the probes, that required long-term recognition and 50 trials that required short-term recognition. When a recognition trial was presented, the participants' task was to decide which picture was new and which was old. After recognition, which was done by a button press (left button if the left was the old stimulus and right if it was the right one), the next trial was presented. This could either be a probe or an encoding trial.

All pictures were everyday, easy-to-name objects, presented in grayscale (7 x7 cm). Each encoding picture was presented for 1000 ms. The recognition trial remained on the screen for 2000 ms, unless the participant responded faster. In that case, the stimulus disappeared immediately after response. The interstimulus interval was 1000 ms for each trial type.

Outcome variables were the number of correct recognitions for each delay (accuracy), as well as the mean reaction time of the responses for the behavior. The amplitude and latency of the P300 and P600 were the ERP outcomes.

### Analysis

#### *DMTS*

Mean reaction time and accuracy were calculated. All behavioral and ERP data were analyzed with GLM repeated measures. Session (1 vs. 2) was taken as within-subject variable, as were for some analyses also stimulus type (short vs. long delay). Also Pearson correlations were calculated for Session.

#### *EEG*

Offline, eyeblink activity was removed from the EEG using the ocular correction method in Vision Analyzer 2 (Brain Products GMBH). Furthermore, trials in which movement artifacts occurred were excluded from analysis. Data were filtered with a band pass of 1 – 30 Hz. The EEG fragments within an epoch of 100 ms before stimulus onset and 1000 ms after onset were averaged, using the pre-stimulus interval as baseline. Separate averages for the two intervals for recognition were made for each of the two sessions. Next, grand averages over participants were calculated for each stimulus type (short delay/ long delay, new/old), from which the following ERP components were determined: P300 (200 – 350 ms) and P600 (450 – 750 ms). For these components latency and amplitude were analyzed. In this paper only data for the PZ electrode are presented.

## RESULTS

### Behavioral data

The mean reaction time and accuracy for all participants are shown in figure 1. A difference is made between first and second session, and between short and long delay stimuli.

Short delay across sessions. A repeated-measures ANOVA with session as repeated measure variable on reaction time and accuracy for short delay stimuli revealed no effect of session (RT: F(1,19)=1.782, p<.199; Acc: F(1,19)=.104, p<.751). These results additionally showed a significant correlation between sessions for reaction time (r=.858, p<.001) and a marginally significant correlation between sessions for accuracy (r=.429, p<.06).

Long delay across sessions. A repeated-measures ANOVA with session as repeated measure variable on reaction time and accuracy for long delay stimuli revealed no effect of session for accuracy (F(1,19)=.435, p<.519) and a significant effect for reaction time (F(1,19)=8.086, p<.011). The results for accuracy revealed a marginally significant correlation between sessions (r=.428, p<.061). The results for reaction time showed a significant correlation between sessions (r=.833, p<.001). Participants were significantly faster in the second session ($\mu_1$ = 970ms, $\mu_2$ = 886ms). Short vs. long delay Session 1. A repeated-measures ANOVA with delay (short vs. long) as repeated measure variable on reaction time and accuracy for Session 1 stimuli revealed a significant effect of delay (RT: F(1,19)=12.030, p<.004; Acc:

F(1,19)=12.388, p<.003). These results were accompanied by significant correlation between delays (RT: r=.913, p<.001; Acc: r=.522, p<.019). Participants were significantly faster and more accurate for stimuli with a short delay, compared to stimuli with a long delay (RT: μ1 = 890, μ2 = 970; Acc: μ1 = .874, μ2 = .815).

Short vs. long delay Session 2. A repeated-measures ANOVA with delay (short vs. long) as repeated measure variable on reaction time and accuracy for session 2 stimuli revealed a significant effect of delay for accuracy (F(1,19)=9.800, p<.007) and no significant effect of delay for reaction time (F(1,19)=1.518, p<.234). The results additionally showed a significant correlation between delays (RT: r=.894, p<.001; Acc: r=.713, p<.001). Participants were significantly better in responding to short delay stimuli compared to long delay stimuli (Acc: μ1 = .868, μ2 = .827).

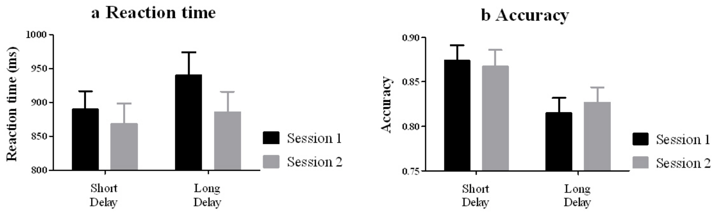

**Figure 1.** Mean reaction time (ms) and accuracy for long and short delays per session.
Figure 1A: significant longer reaction times for long delay stimuli in Session 1 are present.
Figure 1B: no significant effects of session for accuracy were present.

## ERP data

The grand average of the ERP data of this experiment can be found in figure 2. Different lines show different sessions and different delays. The results of the EEG data can be found in figure 3

P300, both delays across sessions. A repeated-measures ANOVA with Session (1 vs. 2) as repeated measure variable on P300 latency and amplitude for short delay stimuli revealed no effect of session (latency: F(1,19)=.236, p<.634; amplitude: F(1,19)=.007, p<.934). Significant correlations between sessions were found (latency: r=.474, p<.036; amplitude: r=.874, p<.001).

A repeated-measures ANOVA with Session (1 vs. 2) as repeated measure variable on P300 latency and amplitude for long delay stimuli revealed no effect of session (latency: F(1,19)=.502, p<.488; amplitude: F(1,19)=1.372, p<.257). The results for amplitude revealed a significant correlation between sessions (r=.855, p<.001). Latency did not significantly correlate between sessions (r=.131, p<.583).

P600, both delays across sessions. A repeated-measures ANOVA with session (1 vs. 2) as repeated measure variable on P600 latency and amplitude for short delay stimuli revealed no effect of session (latency: F(1,19)=.240, p<.631; amplitude: F(1,19)=2.737, p<.115). The amplitude showed a significant correlation between sessions (r=.642, p<.003). The results for latency did not show this correlation (r=.146, p<.541).

A repeated-measures ANOVA with Session (1 vs. 2) as repeated measure variable on P600 latency and amplitude for long delay stimuli revealed no effect of session for amplitude (F(1,19)=.442, p<.515) but a significant effect for latency (F(1,19)=7.181, p<.016). This significant effect can be found in figure 3D. A marginally significant correlation between sessions was found for amplitude (r=.425, p<.063) and no significant correlation was revealed for latency (r=.337, p<.147). P600 was significantly prolonged in Session 1 compared to Session 2 (latency: μ2 = 604ms, μ3 = 550ms).

P300, within sessions. A repeated-measures ANOVA with delay (short vs. long) as repeated measure variable on P300 latency and amplitude for Session 1 stimuli revealed no effect of delay (latency: F(1,19)=.012, p<.914; amplitude: F(1,19)=.176, p<.681). Significant correlations were found between delays (latency: r=.578, p<.009; amplitude: r=.842, p<.001).

A repeated-measures ANOVA with delay (short vs. long) as repeated measure variable on P300 latency and amplitude for Session 2 stimuli revealed no effect of delay (latency: F(1,19)=1.259, p<.277; amplitude: F(1,19)=3.018, p<.100). The results showed a significant correlation between delays for amplitude (r=.964, p<.001) but no significant correlation for latency (r=.140, p<.556).

P600, within sessions. A repeated-measures ANOVA with delay (short vs. long) as repeated measure variable on P600 latency and amplitude for Session 1 stimuli revealed no effect of delay (latency: F(1,19)=1.208, p<.286; amplitude: F(1,19)=.315, p<.582). A significant correlation between delays was found for amplitude (r=.758, p<.001) and a marginally significant correlation for latency (r=.404, p<.079).

A repeated-measures ANOVA with delay (short vs. long) as repeated measure variable on P600 latency and amplitude for Session 2 stimuli revealed no effect of delay (latency: F(1,19)=1.191, p<.290; amplitude: F(1,19)=4.019, p<.060). These results revealed a significant correlation between delays for amplitude (r=.671, p<.002) but not for latency (r=.323, p<.166).

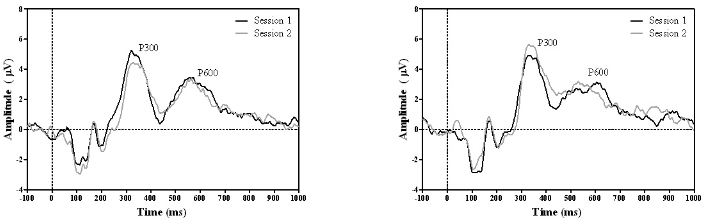

**Figure 2.** Grand Average of the ERP signal of the different delays and different sessions

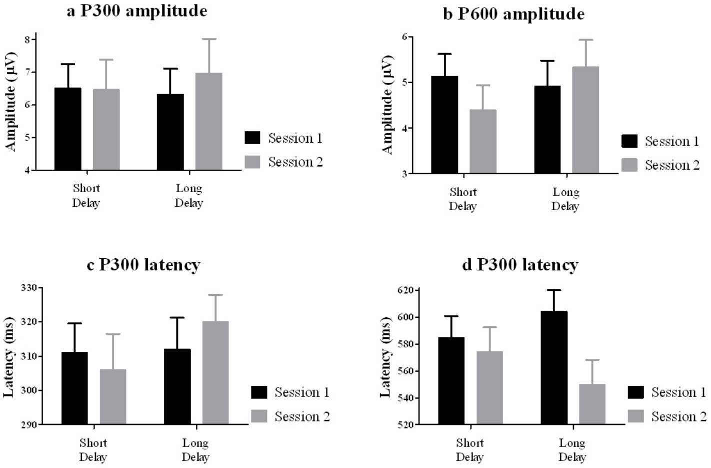

**Figure 3.** Amplitude (µV) and Latency (ms) for P300 and P600 for long and short delay on session.
Figure 3A-3C: the effects of session on the P300 amplitude, P600 amplitude and P300 latency respectively. No significant effects were present.
Figure 3D:the significant effect of session on the P600 latency for long delay stimuli. Other figures show no significant effects.

## DISCUSSION AND CONCLUSION

The aim of this research was to assess stability of visual working memory using the delayed matching to sample task (DMTS). For the first time, a new paradigm was used, which included both short and long delay stimuli, within one paradigm. Comparisons were also made between short and long delay stimuli. Reaction times for long delay stimuli were significantly faster in participants in the second session compared to those in the first session. This difference was also found for P600 latency in response to long delay stimuli, which was longer in the first session. Although behavioral data suggest a significant difference in reaction time regarding long delay stimuli, this difference was accompanied by a high correlation between the first and second session on almost all the other measures. Thus, generally it can be said that the stability of working memory was quite high using this test. As for the comparisons between short and long delay stimuli, participants performed significantly better on short delay stimuli. Only in the second sessions the participants were faster on short delay stimuli. These effects were not found in the EEG signal.

The differences in reaction time between the first and second session for long delay stimuli can be explained in different ways. First of all, it is possible that a learning effect had influence on the reaction time. Learning effects are improvements in performance due to performing a test for a second, third or fourth time (Gluck, Mercado, & Meyer, 2008). A follow-up study can try to eliminate this effect by using two sessions for training before the experimental sessions. A second explanation consists of the development of more suitable strategies, between the first and second session, such as, for example, quickly pressing the button if something is not remembered directly after presentation of the probe trial. In other words, it is possible that participants started to simply quickly guess rather than perform the task properly. This could be avoided by specifically explaining a preferred strategy during instruction. Furthermore, It is possible that participants recognized their relatively long reaction times and tried to find a way to perform faster. This can also explain the fact that accuracy did not improve, but remained stable over sessions. This phenomenon is called speed-accuracy trade-off and is sometimes found in memory studies (Bogacz, Wagenmakers, Forstmann, & Nieuwenhuis, (2010).

Another interesting result is found in the high correlation between reaction time on long delay stimuli between the first and second session. This correlation indicates that all participants improved their reaction time on correct responses, suggesting that there is not a participant-specific change, but a general explanation of the improvement, such as an effect of the novel paradigm itself. This again suggests that task aspects such as additional practice sessions or specific instructions could be modified to reduce these changes between sessions for the long delay stimuli.

The finding that the shorter reaction times are associated with a shorter latency of the P600,.suggests that the P600 is involved in processes that influence reaction time, for example response-selection, executive functioning or decision making. Late positive waves are often associated with response-selection (Friedman, 1990), which is therefore a plausible explanation for the association between reaction time and latency. As compared to the P600, the P300 was very stable over sessions. This corresponds well with previous studies finding high test-retest reliability for P300 amplitude and latency (Hall et al., 2006). The P300, thus, seems to be a stable ERP measure during performance in the DMTS.

From the above, it can be concluded that, responding to short delay stimuli in the DMTS, working memory is stable over sessions, but stability for long delays is absent. Further research could focus on a DMTS with only a long delay, to investigate the idea that this competence improves between two sessions. Changes as compared to the present study should be, e.g., adding an extra practice session, as well as providing specific instructions to all participants. Research could also be done to investigate stability of DMTS-tasks with more different delays. This may explain some of the findings.

## Acknowledgement

This research would not have been possible without our supervisor, Anke Sambeth, who gave us the opportunity to analyze behavioral and EEG data.

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DIMITRA KOSTOGLOU & SACHA LEINDERS

# Mirror Neurons: Findings and Functions

## Review

Mirror neurons (MNs) are a set of premotor neurons that fire both during the performance of a motor action, and the observation of someone else performing the same action. Since their discovery, they have been the subject of great controversy. This survey provides a short overview of the history and the most important findings of MN research in animals and humans. Special focus is given to the latest findings on empathy and relevant disorders i.e. autism, schizophrenia and psychopathy, in the context of MNs. Finally a review of the criticism on MNs is provided and discussed.

**Keywords:** mirror neurons; theory of mind; empathy; autism

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## INTRODUCTION

The human brain consists of countless neurons and neuronal connections, each one distinct in locality and function within the network. It contains neural circuits for all the types of behaviours included in the human repertoire, e.g. comprehension, attention, recollection, daydreaming etc. However, there is one group of neurons that has been a source of huge excitement, as well as great debate since its discovery, i.e. Mirror Neurons (MNs).

Di Pellegrino, Fadiga, Fogassi, Gallese and Rizolatti (1992) found coincidently some neurons in the macaque monkey brain that had the distinct properties not only to fire when the monkey was preforming an action, but also when it observed someone else performing the same action. These neurons were named mirror neurons because they were able to mirror the observed behaviour. Specifically, they fired as if the observer himself was executing the observed action.

An important point to make is that MNs should be differentiated from canonical neurons that reside in the same areas. Both are visuomotor neurons but have distinct properties. Canonical neurons fire when a goal-directed movement is made and when the object related to that movement is observed. On the other hand, MNs also fire when a goal-oriented movement is made, their additional property is firing when someone else is observed doing the exact same movement (Tummolini, Castelfranchi, Pacherie & Dokic, 2006).

MNs are mainly located in the F5 area of the premotor cortex of the macaque brain (di Pellegrino et al., 1992). Initially the research focused on animals, e.g. it was discovered that the monkey's MNs play a vital role in action understanding (Umilta et al., 2001; Kohleret al., 2002). The findings of animal research have set the basis for the research of MNs in the human brain. There is a large amount of literature stating that the human MNS contributes to the evolution of language in humans (Rizzolatti & Craighero, 2004), imitation (Ramachandran, 2000; Oztop & Kawato & Arbib, 2006: Iacoboni, 2005), empathy (Gallese, 2001) and Theory of Mind (ToM ; Gallese & Goldman, 1998). However, other findings suggest that the MNs are just a simple reaction to an observed stimulus without any action-understanding (Hickock & Hauser, 2010). Some other research even suggests that MNs do not exist in humans at all (Turella, Pierno, Tubaldi & Castiello, 2009).

This review surveys the most important findings on MNs. The first section presents and discusses findings concerning MNs in animals, followed by a section on human MNs. After that, research on the relation between empathy and MNs is discussed, along with recent findings in the domain of psychopathology in combination with the MNs. The article concludes with a discussion on the findings, including some of the most important criticism on the MNs, and some final thoughts on potential future research directions.

## FINDINGS IN ANIMALS, THE DISCOVERY OF MN'S AND BEYOND

In 1992 Di Pellegrino et al. investigated area F5 of the macaque premotor brain area. The initial purpose of their study was to differentiate between brain activity induced by presented stimuli and activity related to movements, using single cell recordings. For this technique, micro-electrodes are placed in or near the cell membrane of a neuron, allowing the recording of the activity and the temporal discharge of individual neurons in response to a stimulus (Boulton, 1990). Single cell recordings are therefore a very useful tool for measuring neural activity directly.

By accident, the aforementioned researchers discovered something very interesting: apparently, neurons in the F5 area were activated when the monkey simply observed the experimenter performing a motor action. The researchers focused on investigating this phenomenon further by recording F5 neuron activity during execution and observation of motor actions. These actions were basic motor actions included in the monkey's repertoire, such as actions related to food grasping, the manipulation of objects, and gestures. As expected, almost all of the measured neurons in the F5 area fired when the monkey performed a motor action. Interestingly, the majority of the neurons also fired when the monkey observed a motor action.

After the first experiment, a great amount of research has provided evidence for the location of the MNS and its properties. This research has shown that there appear to be other areas with mirror properties. Besides the premotor area, one of its important input areas, the rostral inferior parietal lobule (IPL) area PF, also contains neurons with mirror properties. The premotor area and the PF are highly interconnected. Most of the PF neurons (90%) respond to visual stimuli, but only half of these neurons are also active during motor actions. The PF sends output to the F5 area and receives input from the superior temporal sulcus (STS; Rizzolatti, 2004). The STS is comprised by visual neurons, which respond to observed biological actions, such as moving faces or bodies (Puce & Perret 2003). Moreover, the STS plays a role in gaze perception and is therefore important in understanding others' direction of attention (Campbell, Heywood, Cowey, Regard & Landis, 1990). Even though the STS has no motor properties and is not considered to be a part of the MNS it is highly involved in the functioning of the mirror neuron system via its connections with inferior parietal parts of the MNS. To conclude, it can be said the cortical MNS in monkeys constitutes the ventral premotor area and the rostral inferior parietal lobule (Rizzolatti, 2004).

More recent research has shown that some neurons can only be activated by observation of very specific motor actions, whereas others fire if the monkey observes motor actions that achieve a similar goal. This led to the conclusion that different types of MNs exist: the strictly congruent MNs (the former) and the broadly congruent MNs (the later). Broadly congruent MNs are higher in quantity than the strictly congruent, occupying approximately two thirds of the MN population (Iacoboni & Mazziotta, 2007).

## FUNCTIONS OF MIRROR NEURONS IN ANIMALS

One of the hypothesized functions of animal MNs is to aid understanding the intention of an observed motor action, as already hypothesized by Di Pellegrino et al. (1992). They found the firing of MNs did not depend on a specific object involved in the motor action or on a specific motor gesture, but on the meaning or intention of the action. Therefore the authors hypothesized that MNs are important for the automatic understanding of goal directed behaviour.

Additional research has provided support for this claim: MNs have the ability to fire for goal directed behavior even when an object is partially hidden. This was found in monkeys (Umilta et al., 2001). Moreover, studies have demonstrated the existence of audiovisual MNs in the monkey premotor area, besides the visual based MNs. This type of neurons has the ability to fire when the animal performs an action and when it hears a sound that is related to that specific action (Kohler et al., 2002).

Further research into the F5 area of the monkey's premotor cortex, specifically the ventrolateral premotor cortex, has demonstrated that the MNs located there fire during the observation of actions made with tools, the so called tool - responding MNs. These neurons fire when the monkey makes a hand or mouth movement, but also when the researchers manipulate a tool.

These neurons are congruent, with the sense that their aim, when they fire, is a manipulation of an object, observed or executed (Ferrari, Rozzi & Fogassi, 2005). Another interesting finding is that one third of the mirror neuron population in area F5 fires when the monkey observes mouth actions. These ''mouth mirror neurons'' fire when the observed movements are related to ingestive functions, but fire more prominently during communicative gestures, e.g. lip smacking. This may underline the importance of the MNs in communication. Interestingly, in humans the homologue of the F5 area is Broca's Area, an area highly involved in language. This could have further implications on how language evolved in humans (Ferrari, Gallese, Rizzolatti & Fogassi, 2003).

Moreover, in a study using single cell recordings researchers measured the activity of the F5 neurons when the action was performed at different distances from the monkey. They found that 26% of the premotor neurons fired when the observed movement was made in the monkey's extrapersonal space, 27% when in the peripersonal, and 47% fired independently of location, in which the observed movement was executed. This indicates that observed actions executed at different distances from the monkey are differently encoded by MNs. These findings have potentially strong implication for social – and potentially human - behavior, since in a social environment is it important to quickly respond to observed behavior based on its location relative to the observer (Caggiano, Fogassi, Rizzolatti, Their & Casile, 2009).

To summarize, animal research has demonstrated that MNs encode an action differently, dependent on the locality with respect to the observer and that MNs fire when the monkey observes mouth movements, when it observes actions made by tools or motor actions that are present in its repertoire.

## THE HUMAN MIRROR NEURON SYSTEM

In the past decade, a considerable amount of research has been done into the human MNs. Besides the main function of goal understanding, the human MNs are often endowed with other functions, such as imitation, language acquisition, and emotion (Fabbri-Destro & Rizzolatti, 2008).

### Techniques used in humans to study MNs

Although single cell recordings are very useful for the study of MNs, they are rarely found in human research since they can only be performed when a patient requiring the insertion of intracranial electrodes agrees to participation in an experimental study (Engel, Moll, Fried, Ojemann, 2005). Before discussing results from human research, it is important to describe briefly the techniques most commonly used in human research for MNs.

Transcranial Magnetic Stimulation (TMS) is a noninvasive technique that is widely used to study MNs in humans. A TMS-device induces a powerful electromagnetic field capable of depolarizing superficial neurons (current max range from brain surface: 2mm), thereby causing these neurons to initiate action potentials (Pascual-Leone, Davey, Rothwell, Wassermann & Puri, 2002). Research has shown that when single or paired pulse TMS is applied to the human motor cortex, it causes a temporary increase in cortical motor excitability (Nitsche & Paulus, 2001). This increase induces contralateral muscle activation called Motor Evoked Potential (MEP), which can be measured from these muscles by electromyography (EMG; Pascual-Leone, et al., 2002). Research shows that when we observe an action, there is a minor, sub threshold increase in activity in the muscles involved in that action, which is most likely caused by MNs (Cattaneo et al., 2009). Because this minor muscle activity can lead to MEPs, TMS is a useful tool to study MNs.

Besides single or paired pulse TMS, it is also possible to stimulate areas using repetitive TMS pulses (rTMS). This leads to longer lasting effects than ordinary TMS. Depending on frequency and the intensity of stimulation, rTMS can excite or inhibit areas (Fitzgerald, Fountain & Daskalakis, 2006). This way it is possible to create temporary, virtual ′lesions′ in human subjects and investigate the functioning of specific brain areas by inhibiting these areas.

Another way of measuring MN activity is through encephalography (EEG). It has been observed that when humans are at rest, there is an 8-13Hz oscillation generated in the sensorimotor cortex. This is called the mu rhythm. When humans observe another individual performing an action, the neurons in the sensorimotor area fire asynchronously, causing a reduction in the mu amplitude. This is named mu suppression and it is considered to be an index of the MN activity (Ulloa & Pineda, 2007).

An additional technique used in human MN research is Functional Magnetic Resonance Imaging (fMRI). fMRI measures changes in cerebral blood flow. Increased neuronal activity leads to higher cell metabolism, which in turn leads to an increased cerebral blood flow in the activated area. fMRI can spatially pinpoint a rise in blood flow to precisions of up to a mm (Huettel, Song, & McCarthy, 2009). Since it has a good spatial resolution, it can be used to measure indirectly neuronal activity in very specific areas. Of course, findings from fMRI and EEG should be interpreted with caution, since there is no direct evidence that the measured activity really stems from the exact same type of MNs as the ones identified in monkeys with single cell recordings. We can assume it is the MNs firing based on function and location deduced from animal research, but unless single cell recordings are combined with fMRI or EEG we cannot say with certainty that the measured activity belongs to the MNs (Rizzolatti & Craighero, 2004).

### Location

In humans, two mirror neuron systems have been identified by brain imaging studies. The first one is situated in the parietal lobe, the premotor cortex and the pars opecularis. The pars opecularis, also called Broca's Area, includes the IPL and the caudal part of the inferior frontal gyrus (IFG) and is a vital area for language. The parietofrontal network is responsible for the recognition of voluntary behavior. Since MNs are largely based in the motor cortex, it is not surprising that just like these motor areas, the MN show a somatotopic organization (Buccino, Binkofski, Fink, Fadiga, Fogassi, Gallese, et al., 2001; Marieb & Hoehn, 2007). The second MN system comprises the insula and the anterior mesial cortex. The limbic mirror system, as it is called, is endowed with the recognition of affective behavior (Cattaneo & Rizzolatti, 2009; Fabbri-Destro et al., 2008). One study that used single - cell recordings in humans, found that MNs are sparse in multiple brain areas. Specifically, they placed electrodes in the medial frontal and temporal cortex in patients suffering from epilepsy. These patients had to execute or observe hand actions and facial expressions. They found that a significant population of the neurons in the supplementary motor area and hippocampus fired both when they observed and executed actions (Mukamel, Ekstrom, Kaplan, Iacoboni & Fried, 2010). This suggests that besides the above mentioned main systems, additional areas in the human brain may have mirror properties.

## Findings and Functions

The first study to report the existence of MNs in the human brain was a TMS study by Fadiga, Fogassi, Pavesi and Rizzolatti (1995). By applying TMS over the motor cortex they found increased MEPs when the participants viewed the experimenter performing hand movements, compared to control conditions. Since then TMS has provided ample evidence for the existence of MNs in humans.

Aziz-Zadeh, Maeda, Zaidel, Mazziotta, and Iacoboni (2002) tested the cortico-spinal excitability when the subjects viewed actions performed either by a left or a right hand, or a control stimulus during left or right motor cortex TMS. When TMS was applied to either the left or right motor cortex, MEPs increased during observation of a contralateral hand stimulus. These results indicate that human MNS fire automatically at the sight of a moving biological agent, like a hand, even in the absence of any motor output. Additionally, these studies indicate that the human brain, just like that of the macaque monkey, possesses neurons that fire during action observation and motor output of that same action.

Research supports the notion that the human MNS is also capable of encoding action intention. Buccino et al. (2004) in an fMRI study showed that motor actions that were in the participants' repertoire (e.g. a dog or a monkey biting something) activated the inferior parietal lobule and the pars opecularis, which are assumed to be part of the Mirror Neuron System, despite the fact that these actions were executed by animals. But when the action was not a typical human behavior, like barking, only visual regions were activated. This demonstrates that the human Mirror Neuron System is activated when an action, that is typical of human behavior, is observed no matter who is the agent of that action. More specifically, this experiment suggests that human MNs fire according to the intention of the action (dog/ monkey - biting), and not just the simple observation of the action itself.

This is further supported by an EEG experiment by Ulloa & Pineda (2007) in which mu suppression was measured. The authors used EEG to show that MNs are capable in deducing actions from sporadic, but meaningful visual input. They used point - light biological animation videos showing either biological human motion, matched scrambled version of this biological motion, or visual white noise. It was found that mu suppression was increased when the participants watched human movement, compared to the other two animations. These findings support the claim that human MNs have a key role in understanding human movements, even based on fragmented visual input.

Another area of the human MNs that has attracted attention is the inferior frontal gyrus, which includes Broca's Area (Fabbri-Destro& Rizzolatti, 2008). Research has linked it with social perception (Keuken, Hardie, Dorn, Dev, Paulus, Jonas, et al., 2011) and action observation and imitation (Molnar-Szakacs, Iacoboni, Koski & Mazziotta, 2005).

Heiser, Iacoboni, Maeda, Marcus & Mazziotta (2003) investigated how essential the IFG is in imitation, using repetitive TMS to inhibit the area. In every trial, two sets of five pulses were applied with a rate of 5Hz to the left and right pars opercularis of the IFG . The results showed that inhibition of these areas by rTMS decreased performance on imitation tasks compared to control tasks, whereas inhibition of control areas (occipital areas) did not. This experiment shows the importance of the MNS, specifically the IFG in imitation behavior. The authors also concluded that Broca's area also plays a role in imitation, being a part of the IFG.

This evidence, that the MNs have a central role in imitation plus the observation that they overlap with Broca's area, a key language area in the human brain (Iacoboni & Dapretto, 2006) has led some to suggest the MNs might be involved in language evolution in humans. Rizzolatti et al. (2004) proposed a theory about this relationship. They suggest that gestural communication embodies meaning, which evolved to simple noises in the beginning and to complex speech later by the imitation capability of our MNs. MNs firing in response to auditory meaningful stimuli have been proven to exist in monkeys (Kohler et al., 2002).

To assess whether the human MNS could also be activated by auditory stimuli Lahav, Saltzman and Schlaug (2007) performed an fMRI study. In this experiment, subjects learned to play a new tune on the piano, which was later played back to them. During both playing and the listening session fMRI data were acquired. They found that the bilateral frontoparietal motor-related network, including Broca's area, was activated during the auditory perception of the newly acquired tune and during its execution. This system, which the authors named the hearing- doing system, depends on the subject's motor repertoire. Newly learned motor acts can be established in this network very quickly, as shown by the activity induced by listening to the newly learned tune. Moreover, this system has Broca's area as a hub. The authors therefore underline that this system might have important implications in language acquisition, as this hearing- doing system serves as an important sensorimotor feedback during speech.

Finally, MNs have been implicated in social interaction. In a study by Oberman, Pineda & Ramachandran (2007) showed that the MNS may play a role in social interaction. Mu suppression in response to four different movies was measured: a non-interacting, non-social movie (Non Social); non-interacting, social (Social Spectator Role); interacting, social (Social Interactive Role); and a control movie (visual white noise). The results were highly significant: the movie which induced the Interactive Role lead to the highest mu suppression (M=- . 22), followed by the Spectator Role movie (M= -.15). The non - social movie led to the lowest mu suppression (M= -.08). These results indicate that the human MNS can encode stimuli with social relevance.

In conclusion, it has still not been directly determined whether the MNs found in humans are of the same type as the animal MNs. However, the studies in humans have provided a great quantity of evidence which makes it safe to assume that neurons with mirror properties at least seem to exist and that these proposed

MNs have implications in action observation, intention understanding, imitation, social interaction and their potential role in language evolution. Besides these implications, the MNs have also been associated with empathy.

## MIRROR NEURONS AND EMPATHY

One of the most important implications of the MNS in humans is its importance in empathy. Some theories suggest that the functioning of the frontoparietal mirror neuron system is vital for the understanding of other people's emotions, implying that dysfunctions may impair empathy.

Empathy is a very broad term, often used in the human sciences, from philosophy and sociology, to psychology and now to neurosciences. This wide usage of this term is the reason that it has multiple definitions, dependent on the perspective one takes. One satisfying definition is that: empathy is "a mechanism for inferring and experiencing, what another feels by simulating it through a shared self- other representation" (Pineda, Moore, Elfeinbeinand & Cox, 2009).

In order to explain its neural mechanism, Blair (2005) suggested that there are three forms of empathy: emotional, cognitive and motor empathy. According to Blair, MNs can account only for the motor empathy of humans, which most importantly includes imitation. Cognitive empathy arises from temporoparietal regions (regions associated with ToM), while emotional empathy depends mainly on limbic regions. All three kinds of empathy interact with each other in order for the individual to be fully empathic. Nevertheless, in this view, the MNs are given a more primitive, purely motor and rather simple form of empathy.

Two other main theories are Theory - Theory (TT) and Simulation - Theory (ST). TT states that individuals can infer the emotional state of another by relying on common theories about behavior or emotion, also known as folk psychology. ST on the other hand, states that in order to understand another person's state, an individual must place oneself in the other person's shoes to know the other person's feelings (Gallese et al., 1998).

Proponents of the ST view suggest that the MN gives humans the ability to simulate other people's intentions and emotions by the mere observation of another individual. It has been found that observation of emotional expressions activate our MN circuit, which can then evoke feelings similar to those observed (Gallese et al., 1998; Kaplan et al., 2006; Gallese, Eagle & Migone, 2005).

Finally, another view states that MNs are the neural substrate of ToM. ToM is closely related to empathy and has its roots in philosophy. It proposes that people have the knowledge that mental or emotional states are different among individuals and are able to acknowledge them. These inner states can be emotions, goals, perspectives, knowledge, etc. (Agnew, Bhako, & Puri, 2007). Research has shown that ToM is clearly dysfunctional in people with Autism Spectrum Disorder (ASD; Baron-Cohen, Leslie & Frith, 1985). Moreover, research has shown that people diagnosed with ASD have dysfunctional MNs (Williams, 2008). This is why some researchers believe that dysfunctional MNs may be one of the main causes for autism (Rizzolatti et al., 2009).

## IMPAIRMENTS IN MIRROR NEURON SYSTEM AND SOCIAL DISORDERS

### Autism

The link between MNs, ASD and empathy has been researched extensively and the ''broken mirror'' hypothesis has been researched by Oberman. In their study, Oberman et al. (2005) found that MNs are dysfunctional in highly functioning individuals with ASD. In this experiment the subjects watched four different videos showing a moving hand, a bouncing ball, visual noise or a movement of their own hand. They found a lack of mu suppression in the sensorimotor cortex of ASD patients, compared to unimpaired controls, during the first and fourth condition. The authors state that although ASD patients showed normal mu suppression during hand movement, they failed to show any during both conditions of hand movement observation, which indicates a dysfunction in the MNs. Moreover, they propose this finding may also be related to the deficits ASD patients show in imitation and ToM.

Support for the above finding is provided by Williams et al. (2005) who showed in an fMRI study that patients with ASD have an impaired MN circuit activation. In their experiment participants had to execute movements with their fingers directed by a symbolic cue or imitate the same actions by watching pictures of fingers. They found that although participants with ASD activated their MN circuit in the anterior parietal area, they did so to a lesser extent than controls in the second condition. Moreover, the patients showed less activation than expected in the somatosensory cortex and no modulation of the left amygdala during imitation. This led the researches to hypothesize that patients with ASD may still have the primary function of imitation intact. However, their MNS may not be capable enough to skillfully employ empathy and ToM.

Another view proposes that the parietofrontal MNs is highly connected with the limbic MNs, which may provide a system sufficient for understanding the emotion of others (Cattaneo et al., 2009). The limbic system is known for its implication in emotional situations (Isaacson, 2001). The proposed MNs-limbic network comprises the frontal MNs, the insula and the amygdala and it is thought to facilitate the understanding of others′ emotions through action representation. This system is found to be dysfunctional in people with autism and this dysfunction is thought to be responsible for the lack of empathy and social understanding (Dapretto et al., 2006; Iacoboni, 2005).

To conclude, most of the evidence suggests that MNs are dysfunctional in ASD patients. However, based on the available literature it cannot be concluded whether there is a causal relation between a dysfunctional MNs and ASD, or whether dysfunctional MNs are the result of other symptoms related to ASD.

### Schizophrenia

Schizophrenia is a psychotic disorder with a mixture of positive symptoms (such as delusions or hallucinations) and negative symptoms (such as affective flattening, alogia and avolition; DSM-IV-TR, 2000). How is this disorder related to the malfunction of the MNs? Arbib and Mundhenk (2005) proposed that the malfunction of the MNs is associated with the positive symptoms of schizophrenia, especially hallucinations, because schizophrenia patients are not able to identify the generation of thoughts or actions as their own.

In one study, schizophrenia patients could not discriminate their own hands from someone else's, stating sometimes that the foreign hand was their own (Buccino & Amore, 2008). This led Arbib and Mundhenk to suggest that these patients had impaired self- monitoring. This impairment was associated with an inability to effectively recruit the MNs, which was potentially caused by a deficit in working memory. Specifically, they suggested that the patients could not form memory traces of their own actions. This, in turn, led to a decreased recruitment of their MNs. This may be a reason for attributing the initiation of their own actions to others. Although MN deficit does not have a primary role in schizophrenia, it is proposed that it is a result of working memory dysfunction.

### Psychopathy

Psychopathy is defined as the inability to feel what others are feeling along with the characteristic to manipulate people (Blair, 2005). To date only one study investigated the direct link between MN activity and psychopathic traits.

Fecteau, Pascual-Leone & Théoret (2007) conducted a study in a non-psychiatric sample, where they investigated MEPs using TMS. The participants watched four different videos: a static right hand; a needle penetrating the skin of a right hand; a needle penetrating a fruit; and a cotton stick touching a hand. TMS pulses were delivered at two different time points: in the short condition the TMS pulse was delivered one second after the film started (before needle/stick penetrates/contacts object); in the long condition, three seconds after the beginning of the film (during penetration/contact).

Results from MEPs in the long condition were correlated with scores on the Psychopathic Personality Inventory (PPI). The results indicated that people with higher levels in the cold-heartedness scale of the PPI, showed greater MEP reductions while viewing the video penetrating the hand (emotional video), compared to participants with lower scores on that scale. As cold-heartedness is considered a gold standard for the diagnosis of psychopathy, this finding suggests that people with high scores on psychopathic traits show less motor empathy in response to observed pain than control subjects. Even though the only experiment so far investigating the relation between MNs and psychopathy only investigated psychopathy traits in a non-psychiatric sample, it seems to indicate that there may be a relation between psychopathy and dysfunctional MNs.

## DISCUSSION

The MN discovery has been characterized by many as the most prominent discovery of the past decades. Ramachandran (2000) said: "I predict that mirror neurons will do for psychology what DNA did for biology: they will provide a unifying framework and help explain a host of mental abilities that hitherto remained mysterious and inaccessible to experiments". But more than a decade after their discovery: did they really explain these mysterious mental abilities? And is there even a consensus about the existence of MNs in humans?

### Do We Have Mirror Neurons?

From the MN experiments, the majority does not concern experiments on humans, but on monkeys (Pascolo, Ragogna & Rossi, 2009). MNs were first found in monkeys using single cell recordings (Di Pellegrino et al., 1992). Until single cell recordings are combined with fMRI or EEG we cannot say with certainty that the measured activity in humans belongs to the same type of MNs found in monkeys. Even one of the researchers who originally found the MNs states in his article that direct evidence of MNs in humans is still missing, only indirect evidence has been obtained (Rizzolatti et al., 2004). There have been no adequate studies to certify that MNs similar to those found in monkeys really exist in the human brain. So far a To what degree the exact location of these neurons corresponds to animal areas and other areas identified in human MN research remains to be seen.

### What Mental Abilities Can Mirror Neurons Explain?

Like in monkeys, research has associated the proposed human MNs with action understanding (Buccino et al., 2004). Besides this basic ability, other implications of MNs in humans are imitation (Ramachandran, 2000; Oztop & Kawato & Arbib, 2006: Iacoboni, 2005), language acquisition (Rizzolatti & Craighero, 2004), empathy (Gallese, 2001), and ToM (Gallese & Goldman, 1998). Furthermore, MNs dysfunctions have been implicated in social disorders, like autism (Oberman et al., 2005), schizophrenia (Arbib and Mundhenk, 2005) and psychopathy (Fecteau et al., 2007). However, whether there is a causal relationship between the MNS and the disorders is not entirely clear and requires further research.

### Future Research

Most importantly, to bridge the gap between animal and human findings and to establish whether MNs in humans are the same type of neurons as the ones found in animals, single cell recordings should be combined with imaging techniques like fMRI and EEG either in humans or animals. This way human MN research will have a stronger scientific foundation than the indirect evidence and assumptions it is mainly based on now.

Also, future research on the MN topic should focus on clearly defining and accurately localizing the mirror neurons in humans. Currently, not all studies agree on the exact subareas of the MNS involved in certain types of behavior. For instance, a meta-analysis was conducted on fMRI studies for the implication of MNs in imitation. They identified the inferior parietal lobule and the dorsal part of the premotor cortex as areas systematically involved in imitation. The role of the pars opecularis and the frontal area, which are cited to be crucial for imitation by other researchers, were questioned by this meta-analysis (Molenberghs et al, 2009).

Some MN studies in humans show methodological limitations: brain activity was not always measured during both observation and execution (e.g.: Saltzman and Schlaug, 2007; Ulloa & Pineda, 2007). In most of the experiments the subjects were instructed just to observe an action and not to execute it. This is a limit, since it identifies only the area responsible for observation of an object or action, which may differ from the area responsible for execution as well as the observation (Turella et al., 2009). It is important that the study of MNs is oriented towards populations that have deficiencies in ToM or empathy, for instance people diagnosed with ASD, schizophrenia of psychopathy. It should be investigated if the MNs dysfunction in such cases is a side effect from another abnormality or the main factor of the disorder. The clinical applications, if found, should be consolidated and expanded.

## Closing Remarks

The criticism on the MNs from its rivals is as robust as the enthusiasm from its followers. In the past decades, perhaps no discovery has given more expectations to the psychological community than the MNs. However, the mirror neurons and their potentials do not yet rest on solid ground and still remain a mystery. We hope future research will be able to clarify the main uncertainties, discard the inconsistencies apparent in some of the MN findings and lead to more insight in the role of the MNs.

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LEON SKOTTNIK

# The function of the medial prefrontal cortex in emotions and empathy

REVIEW

Several approaches divide empathy into emotional and cognitive subparts. The emotional reactions are strongly related to the mirror neuron system and interact with cognitive processes as the theory of mind. The aim of this review is to investigate the relationship between empathy and emotions. For this reason the review focuses on the medial prefrontal cortex (mPFC), because it is involved in empathy, emotion regulation, and self-conscious emotions. Overall, it can be concluded that mPFC distinguishes between self-generated emotions and empathy-generated emotions based on a self-other distinction. These findings suggest a shared network of empathy, emotion regulation and self-conscious emotions in cortical regions.

**Keywords:** medial prefrontal cortex; empathy; emotion regulation; self-other distinction; theory of mind

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## INTRODUCTION

Social affective cognitive neuroscience is a relatively new branch of neuroscience with growing interest to the public. It focuses on the role of emotions in a social context. However, brain functions in social situations are also influenced by cognitive processes. It remains to be specified how these cognitive processes are connected to emotional reactions during social events. Concerning empathy, several theories suggest a two stream model divided into emotional and cognitive routes (de Waal, 2008; Rizzolatti & Sinigaglia, 2008; Decety, 2011). During emotional empathy, the emotion of another person is simulated automatically in the observer by activating limbic structures responsible for the given emotion. Considering that emotional empathy and emotions recruit the same macro-anatomical regions it is an ongoing discussion whether these processes share neural populations or even single neurons (Decety, 2011; Rizzolatti & Sinigaglia, 2008; Csibra, 2007). In general, single neurons which are similarly active in observing and performing an action are known as mirror neurons. This creates the possibility of understanding the movements of others automatically because the observed action directly activates the equivalent motor response in the observer.

Although it is well documented that mirror neurons exist for motor behavior (Rizzolatti & Sinigaglia, 2008) it remains to be specified in how far mirror neurons contribute to the understanding of emotions in empathy.

Nevertheless, empathy is not a pure mirroring mechanism. For example, if two persons collaborate in a card game and a frowning face is presented, an empathic reaction will be evoked, signaled by a medial frontal negativity (MFN). By contrast, if the two persons have a competing relation, the same facial expression evokes a much stronger MFN, demonstrating a different evaluation of the affective state (Yamada, Lamm, & Decety, 2011). This example illustrates how cognitive processes change automatic reactions to other peoples' emotions. Still, it remains to be analyzed which cognitive processes are the basis of these phenomena.

Regarding cognitive processes in empathy, the main theories have focused on the interaction between the Theory of Mind (TOM), perspective taking and emotional empathy (de Waal, 2008; Decety, 2011). Nevertheless, empathy is not the only mechanism in which emotions and cognition interact. Other processes such as emotion regulation or self-conscious emotions also depend on emotional and cognitive information. So far, there exists no coherent overview on how empathy is related to other cognitive-emotional processes.

To extend the existing theories, the current review will examine cognition-emotion interactions in empathy, self-conscious emotions and emotion regulation. Furthermore, it will discuss the possibility of an emotional mirror neuron system (MNS) and its connection to cognition.To restrict the amount of information this review will focus on one region of interest, namely the medial prefrontal cortex (mPFC) as it contributes to facial perception (Mattavelli, Cattaneo, & Papagno, 2011), emotion regulation (Kim & Hamann, 2007), empathy and the TOM (Decety & Jackson, 2004; Keysers & Gazzola, 2007, Völlm et al., 2006; Mitchell, Banaji, & Macrae, 2005).

## THE FUNCTION OF THE MEDIAL PREFRONTAL CORTEX IN EMOTIONS AND EMPATHY

Affective and cognitive information are strongly interconnected, especially in empathy. Empathic processes use information of emotional states, as well as cognitive information as the TOM (Decety, 2011). Considering their similar functions and their interdependence it seems likely that emotion and TOM processing share functional regions which will be described in this review.

## The mPFC controls basic emotions

Although it has been repeatedly shown that the mPFC seems to play a role in higher cognitive functions as the TOM (see for example Fletcher et al., 1995; Frith & Frith, 1999; Castelli, Happe, Frith, & Frith, 2000; Völlm et al, 2006) and response selection when several choices are possible (Rushworth, 2008), it is also strongly involved in controlling basic emotional reactions.

Previous animal research suggested that the mPFC is functionally connected to the limbic system (Diorio, Viau, and Meaney, 1993; Milad, Vidal-Gonzalez & Quirk, 2004). This was confirmed for humans by a study on fear regulation using fMRi (Ochsner, Brunge, Graff & Gabrieli, 2002). In this experiment, aversive pictures were presented while subjects should increase, maintain or decrease their emotional reaction to the pictures. To modulate their emotional reaction, subjects reappraised the emotional relevance of the stimulus. As reappraisal requires attention, a control condition was included in which subjects attended to the stimulus without altering their emotional reaction. Strong aversive pictures showed an increase in amygdala and insula activation. Amygdala activation was significantly higher during the control condition compared to reappraisal. Interestingly, the dorsal mPFC was the most active region for high emotional pictures using a reappraisal > attention contrast. Similarly, a study by Zotev at al. (2011) revealed functional connectivity between the mPFC and the amygdala. Subjects had to decrease their amygdala activation by retrieving positive autobiographical memories while receiving real-time fMRI biofeedback of their amygdala. Post-processing showed a negative correlation between amygdala and mPFC activity which became stronger over training trials.

As the mPFC is important for emotion regulation it may also have a function in regulating emotional empathy which also recruits limbic areas. This assumption is supported by an fMRi experiment of Peelen, Atkinson, and Vuilleumier (2010) which demonstrated abstract emotional processing in the mPFC in response to social stimuli. They observed brain activity in response to the perception of basic emotions across different modalities, including face movements, body movements and vocal intonations. Emotional categories included anger, disgust, fear, happiness and sadness and subjects rated the emotional intensity of each stimulus. Multivoxel pattern analysis revealed a differential activation of voxels in the mPFC between emotional categories. However, there was no difference between modalities. The perceived intensity of emotional stimuli was also not correlated to mPFC activation. Peelens' (2010) experiment reveals important insight into the functional properties of the mPFC, namely that the mPFC is also active in perceiving other people's emotions, based on a cognitive level as its activation is not influenced by the modality or emotional intensity.

## The mPFC in self-conscious emotions

The emotional content of primary emotions is mainly focused on the own mental state and does not require an understanding of others or the self (Lewis & Haviland-Jones, 2000). During ontogeny, children have to develop a concept of the self to reach the next level of emotional development. Once achieved, the self-conscious emotions develop, which are empathy, envy, embarrassment, pride, shame and guilt (see for example Slater & Lewis, 2002). Additionally to empathy, the mPFC seems to play a role in many of these emotions. In an fMRi study of Takahashi, Yahata, Koeda, Matsuda, and Asai (2004) subjects were instructed to read sentences with neutral, guilty or embarrassing content. The mPFC showed significantly higher activation in the guilt and embarrassment conditions compared to neutral sentences.

However, in a following study of Takahashi and colleagues subjects had to read sentences with joy or pride evoking contents (Takahashi, Matsuura, Koeda, Yahata, & Suhara, 2008). In contrast to the expectations, no activation of the mPFC was observed in both conditions. Concerning the joy condition it is reasonable that no mPFC activation was found because no social cognition, empathy or emotion regulation was required in this task and joy is no self-conscious emotion.

Contrasting to Takahashi et al.'s (2008) results on pride, an fMRi study by Zahn et al. (2009) found mPFC activation in response to pride by using a more pronounced paradigm. In this study, subjects viewed sentences containing both the subject's name and their best friend's name. The sentences described either a behavior of the subject towards the friend (self-agency) or vice versa (other-agency). During scanning subjects rated sentences on how pleasant the depicted events were. After this, subjects labeled each sentence according to four possibilities: Self-agency in accordance with social values, other-agency in accordance with social values, self-agency counter to social values and other-agency counter to social values. Pride was defined as self-agency in accordance with social values and guilt as self-agency counter social values. The conditions used for analysis were therefore individual for each subject, depending on the subjects' moral sentiments. Thereby, it was controlled for interindividual differences in moral evaluation of the situations. Results showed significant activation of the ventromedial PFC in pride vs. fixation and guilt vs. fixation. The disagreement between Takahashi's (2008) and Zahn's (2009) study may be caused by the fact that Takashi and colleagues predefined which sentences stimulate pride. This definition may deviate from the subject's own evaluation of the stimulus.

## The mPFC and cognitive control of affective and empathic reactions

This section will describe the relationship between empathy and emotions concerning the function of the mPFC. The similarities of empathy-regulation and emotion-regulation will be related to the cognitive processes which are responsible for coordinating both.

### *The relationship between mPFC functioning in empathy and emotions*

To investigate the role of the mPFC in empathy it seems valuable to compare emotion processing to empathy because the mPFC shows the following functions in both processes. First, the mPFC is a central structure in a network responsible for combining affective and cognitive information during emotions and empathy (Keysers & Gazzola, 2007; Decety, 2011; Kim & Hamann, 2007). Second, the mPFC is strongly connected to the emotional regions which are not only involved in affect production but also in empathy such as the amygdala and the insula (Milad et al., 2004; Chiba et al., 2001; Kim & Hamann, 2007; Preston & de Waal, 2002). Thirdly, the mPFC is directly involved in the processing of facial expressions (e.g. Mattavelli et al., 2011) and the TOM (Völlm et al., 2006) which is important for empathy and self-conscious emotions. Fourthly, several independent approaches to empathy suggest a controlling function of higher cognitive regions including the mPFC on emotion sharing in empathy (Preston & de Waal, 2002; Decety 2011, Rizzolatti & Sinigaglia 2008). Similarly, during emotion regulation the mPFC is responsible for controlling emotional reactions (Ochsner et al., 2002; Zotev et al, 2010; Kim & Hamann, 2007; Decety & Jackson, 2004). Fifth, during social fear learning in rats a combination of emotional-motivational and empathic information produces a shared mPFC activation (Olsson & Phelps, 2007).

### *Differentiating between empathy and emotions: The self-other distinction*

Although empathy and emotions share several functional similarities they remain distinct processes. The distinction between empathy and emotions is of special importance for emotional empathy in which the emotional state of another person is simulated in the observer (de Waal, 2008). The question arises why this simulation is not confused with own emotions as in both processes the same regions are activated (see for example Singer et al., 2004). This question was addressed in a theoretical approach on empathy by Decety (2011) and Decety and Jackson (2004). Decety proposes three main mechanisms as bases for empathy, namely self regulation, emotion understanding and affective arousal/sharing of emotions. In this model, cognitive understanding of emotions includes perspective taking and TOM processes and is strongly related to the mPFC. Affective arousal describes automatic affective reactions to simple emotional stimuli and it is mainly performed by the limbic system. Sharing of these automatic reactions describes the taking over of another person's emotion comparable to a mirroring mechanism. During self regulation the emotional reactions are regulated by cognitive processes in the mPFC to fit empathic response to the social context (Decety, 2011). However, it remains to be investigated which cognitive processes are involved in self regulation during empathy. An important cognitive mechanism in this context is the distinction between the self and others because it ensures that empathic emotions are not confused with own emotions (Decety and Jackson, 2004).

Interestingly, recent studies have suggested that the mPFC is important in distinguishing between the own mental state and the mental state of others. For example, in an fMRI experiment by Ochsner et al. (2004) subjects had to evaluate social-emotional pictures on three aspects. First, they had to judge their own emotional reaction to the picture. Second, they had to evaluate the emotional state of the central person of the picture. Third, they had to indicate whether the picture was taken inside or outside as baseline measurement. The results showed that the first and the second conditions activated the mPFC compared to the baseline. In condition one, sub-regions of the mPFC and the left temporal cortex were active, compared to condition two. In contrast, the left lateral prefrontal cortex (including Broca's area), the medial frontal gyrus and the medial occipital cortex were activated in condition two. These findings suggest that the cognitive representations of the own and someone else's emotional state rely on two distinct networks and that the mPFC contributes to both. However, it remains unclear what the exact function of the mPFC is in this context (Ochsner et al., 2004).

### *Connections between the mPFC and the affective MNS*

Interpreting Ochsner et al.'s (2004) findings with Decety and Jackson's (2004) approach, the mPFC activation would discriminate between emotions and empathic reactions based on the self other distinction. By this, the mPFC would influence the activation of emotional core regions involved in empathy and emotions.

However, not only macro-anatomical structures but even the same neurons may be active during emotions and empathy. These neurons are defined as affective mirror neurons. Potentially, affective mirror neurons could be found in every region that is active in empathy and emotions. It remains to be investigated whether affective mirror neurons exist and how the mPFC is connected to them.

This topic was addressed by an fMRi study by Schulte-Ruther and colleagues (2007) which indicates that the mirror neuron system (MNS) is related to the self-other distinction in the mPFC. In this study, subjects performed two different tasks with faces (either directed towards the observer or adverted by $45^0$) expressing anger, fear, sadness, disgust, happiness or no expression. In the other-task subjects indicated the emotional state of the person. In the self-task subjects indicated their own emotional reaction to the facial expression. An additional high level baseline condition included a gender and age decision task of neutral faces. Before scanning general empathy scores of the subjects were assessed by using the Balanced Emotional Empathy Scale (BEES) and the Empathic Concern Scale (ECS). There was no difference in activation across face emotions and the authors concluded that their paradigm only tested a general mechanism for face perception, not specific enough to activate different emotional representations. The results also showed that the left lateral orbito-frontal cortex, the mPFC, bilateral inferior frontal cortices, superior temporal sulci, temporal poles, and the right cerebellum were involved in both the "self" and the "other" task compared to baseline. The "self" compared to the "other" task differentially activated the mPFC (see also Heatherton et al., 2006). Significant activation differences between the self vs. other task were also found in the inferior frontal gyrus (see also Ochsner et al., 2004). Remarkably, the iFG activity correlated with empathy scores. Importantly related to these findings, Kilner and colleagues found evidence for motor mirror neurons in the inferior frontal gyrus (Kilner, Neal, Weiskopf, Friston, & Frith 2009). Taken together these studies reveal functional connectivity during empathy between the mPFC and regions related to the MNS based on the self-other distinction.

Furthermore, the activation of the mPFC in TOM tasks (Völlm et al., 2006) and its functional connectivity to other regions associated with the TOM (especially the STS and the temporal parietal junction) suggests a contribution of the self-other distinctions to the TOM (Saxe & Kanwisher, 2003; Mitchell et al., 2005; Schulte-Rüther et al., 2007). Therefore it seems plauslible that the TOM influences the MNS based on the self- other distinction (Schulte-Rüther et al., 2007). Other examples for connections between MNS related regions and the mPFC are reflected by projections from the mPFC to the insula and the anterior cingulate cortex (Chiba et al., 2001). Remarkably, Hutchison, Davis, Lozano, Tasker, and Dostrovsky (1999) found evidence for affective mirror neurons in the human ACC using single cell recording. During surgery in epileptic patients they delivered pain stimuli to the patients. A class of neurons was selective for pinprick stimuli and responded when the patient received the stimulus and also when they viewed the experimenter receiving the stimulus. Furthermore, evidence for mirror neuron activity in the insula is based on fMRi studies by Wicker et al. (2003) and Singer et al. (2004).

## Self-other distinction based regulation of emotions and empathy

To summarize the findings presented in this paper, the author proposes the following model (see Figure 1). Most fundamentally, the mPFC is involved in controlling emotional reactions (Davidson., Putnam, & Larson, 2000; Diorio et al. 1993) which are produced in emotional core regions such as the amygdala, insula and the cingulate cortex (Olsson & Phelps, 2007). Similarly, the mPFC regulates emotional empathy and possibly the affective MNS (Hutchison et al., 1999; Singer et al., 2004) based on the self-other distinction (Decety, 2011). The mPFC controls affective and empathic responses by distinguishing between the self and others. In accordance with this, various theories have suggested that the self-other distinction controls affect processing by signalling whether an emotional response is internally or externally generated (i.e. the self-other distinction reflects whether the current emotional reaction is produced by empathy or whether it is an own emotional reaction) (Schulte-Rüther et al., 2007; Keysers & Gazzola, 2007; Decety & Jackson, 2004).

The main function of the mPFC in the TOM is to compare self and other related information (Mitchell et al., 2005; Schulte-Rüther et al., 2007; Keysers & Gazzola, 2007). Evaluating the self in relation to others is crucial in self-conscious emotions and depends on the TOM (Takahashi et al., 2004; Takahashi et al., 2008). By evaluating the self in relation to others the mPFC activates emotional core regions such as the amydala and the cingulate cortex during self-conscious emotions (Ruby & Decety, 2003). The self-other distinction is therefore a crucial functional connection between cognitive and emotional information in empathy and emotions. This is in accordance with de Waals (2008) evolutionary approach to empathy, which states that the self-other distinction characterizes social cognition but also influences emotional empathy.

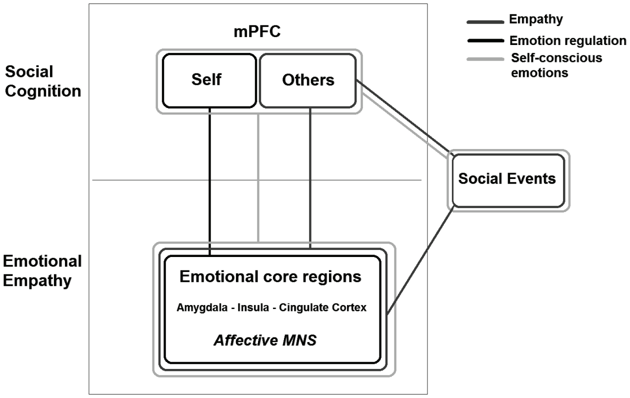

**Figure 1.** The self-other distinction regulates emotions and empathy.

The self-other distinction differentiates between empathy, emotion regulation and self-conscious emotions. Emotional empathy shares regions with basic emotional reactions whereas social cognition is built on the self-other distinction which is crucial for self-conscious emotions.

## CONCLUSION

Two distinct neural circuits form the neural basis of empathy (de Waal, 2008). The first pathway is used for fast reactions to social-emotional stimuli and contains the medial prefrontal cortex and basic emotional structures such as the amygdala and the insula. The second pathway contains prefrontal (including the medial prefrontal cortex) and cingulate cortex regions. The cortical pathway controls the automatic reactions of the first pathway based on cognitive processes (Olsson & Phelps, 2007). The mPFC is embodied in both pathways, suggesting that it is an important structure for connecting emotions and cognition.

In this review the relationship between affective and cognitive information processing in the mPFC was analyzed. Cognitive processes in the mPFC seem to be fundamental for making self-other distinctions (Mitchell et al., 2005). Distinguishing between the self and others is crucial in the TOM, empathy and perspective taking (Mitchell et al, 2005; de Waal, 2008). It is further suggested, that the self-other distinction is crucial for controlling automatic subparts of empathy (Keysers & Gazzola, 2007). More precisely, recent studies suggest that the mPFC may control parts of the affective mirror neuron system (e.g. Schulte-Rüther et al, 2007). This seems necessary, because the affective response has to differ if an emotional reaction is one's own emotion compared to a simulation based on mirror neuron activity (Decety & Jackson, 2004). Besides reactions to emotions of others, the mPFC also is active in regulating one's own emotions and basic affective responses of sadness, disgust, fear and happiness (Milad et al., 2004; Kim & Hamann, 2007). Additionally, the mPFC and connected regions (especially the STS) are involved in self-conscious emotions by evaluating the self in relation to others based on the TOM (Takahashi et al., 2004; Takahashi et al., 2008). Summarizing, the presented studies suggest a similar function of the mPFC and related subcortical regions in empathy/TOM and in emotions.

To verify the implementations of these conclusions further, mPFC activation should be compared between empathy/TOM and emotion regulation tasks. The influence of the mPFC on the human mirror neuron system should furthermore be observed in more detail, as there is much debate on the function of mirror neurons in empathy.

In general, there is still much need for further research and finer theoretical differentiations. Firstly, the mPFC can be subdivided in several functional subparts. Differences between ventral and dorsal sections of the mPFC seem crucial (Decety, 2011) but also other differentiations should be taken into account.

Secondly, the cognitive level on which the mPFC operates remains undefined. For example a meta-analysis by Wager, Jonides, and Reading (2004) demonstrated the activation of the mPFC in different task-switching studies. Wager et al.'s meta-analysis compared task switching paradigms that used different types of task switching (e.g. switching attention between the shape vs. colour of an object or switching between two earlier learned rules which both applied to one object). mPFC activation was found in nearly all task switching types. Thus, the findings of Wager et al. suggest that the mPFC contributes to the switching between abstract mental sets in general. However, it remains to be specified how these content independent processes are related to emotion processing.

Thirdly, the studies presented in this review mainly focus on the mPFC. Although the mPFC seems to be the crucial structure in this context, probably many other regions are involved. As the STS is strongly connected to the mPFC and involved in the TOM and self-conscious emotions it could be another structure of interest (Takahashi et al., 2004). Furthermore, the iFG remains a region of special interest as it is related to the MNS (Kilner et al., 2009) but also active during self conscious-emotions (Simon-Tomas et. al, 2011).

Fourthly, it remains unclear to what extent empathy is based on affective-mirroring systems or motor-mirroring systems. Therefore, the research on the human mirror neuron system should be interpreted more carefully. For example, many studies claim to demonstrate mirror neurons but only find a common activation of one region. However, a common activation of a region does not imply that the same neurons are active although several studies interpret it that way (Schulter-Rüther, 2007). This is mainly due to the fact that fMRI lacks the spatial resolution to investigate mirror neurons directly. As single cell recording can only rarely be used in humans, inferences on human mirror neurons are indirect by using TMS, fMRI with adaption paradigms (Kilner et al., 2009) or multivariate pattern analysis (Schulte-Rüther et al., 2007) which is in state to reveal sub-voxel activation (Mur, Bandettini & Kriegeskorte, 2009). Remarkably, the study mentioned by Hutchison demonstrated affective mirroring activity by using single cell recording in humans (Hutchison et al., 1999). It also has to be mentioned that the concept of mirror neurons is not necessary for self-other distinction based regulation of empathy as the distinction may control different neural populations within a functional area. Furthermore, it remains to be analyzed in how far single neuron activity is informative to investigate complex social processes as they probably recruit a huge amount of distributed neural populations. Nevertheless, it is crucial to clarify the existence of affective mirror neurons to understand the neural basis of empathy.

Finally it has to be mentioned that the content of this review describes a fundamental problem for every topic in neuroscience that deals with emotion; that the influence of cognitive information on affective information is widely undefined (Lemerise & Arsenio, 2000). This review presents potential regions and cognitive processes which could contribute to this issue.

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SYLVIA KREUTZER

# How our brains are wired: Are the applications of diffusion imaging useful given the current limitations?

## Review

Diffusion imaging (DI) enables researchers to study white matter (WM) pathways in the human brain in-vivo by labelling water molecules and measuring their diffusion into different directions. Connectivity patterns are inferred assuming that water diffuses rather along than across fibre bundles. This paper introduces the concept of DI, addresses suitable applications and evaluates gains versus limitations. Common applications are (1) generating WM atlases, (2) mapping connectional models of functionally subdivided brain regions, (3) linking disorders to connectivity abnormalities, (4) verifying WM pathways from animal studies, (5) linking personality traits to particular connectivity patterns, (6) measuring structural changes resulting from experience or ageing and (7) presurgical planning. Despite limitations like the moderate spatial resolution, or – more fundamentally – the lack of a gold standard and the kissing/crossing problem, DI can be regarded as a useful tool if researchers choose methods carefully and consider the known limitations.

**Keywords:** DTI; in-vivo; diffusion imaging; WM; connectivity

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## INTRODUCTION

Diffusion imaging (DI) has become popular over the last decades as an effective tool to measure water diffusion in the human brain in-vivo in order to infer white matter (WM) connectivity patterns. Due to its unique possibilities, several new applications - like the human connectome project – have arisen. Initiated in 2009 by the United States' National Institutes of Health (NIH), the human connectome project aims at mapping the complete structural and functional neural connectivity of the human brain within five years. One of the program's goals is to optimize DI techniques and to improve and validate methods of analysis. Special software that can deal with such a great amount of data is required as well, which poses a great challenge to the research teams from nine different institutions that are involved in the project. If a way is found to map all the connections and to structure them conveniently and in an easily accessible way, new possibilities for studying relations between neural connectivity and neurological and psychiatric disorders arise (NIH Human Connectome Project, 2010).

Many more new possibilities have emerged out of DI. The current article gives an outline of how DI works and how the DI data can be visualized. Further, tractography which is used to reconstruct fibre pathways is introduced. Afterwards, methodological and technical limitations of in DI are specified. In the last section, a number of applications is presented and it is discussed whether they are useful given the earlier introduced limitations of DI in general and the different models and algorithms in particular.

## DATA REPRESENTATION IN DIFFUSION IMAGING

### The Underlying Principle

At room or body temperature, water molecules move due to thermal energy, a phenomenon that is called Brownian motion (Einstein, 1956). If they move equally into all directions, this is called isotropic diffusion. In the brain, however, water diffusion is restricted by tissue barriers and anisotropic (Beaulieu, 2002). It is assumed that water molecules diffuse along axons rather than perpendicular to them (Johansen-Berg & Rushworth, 2009). Consequently, measuring diffusion with Magnetic Resonance Imaging (MRI) allows to infer the location of WM bundles.

The MRI scanner can be used to generate anatomical (MRI), functional (fMRI), and diffusion images of the brain. These different modalities are possible because the scanner can be tuned by using different scanning sequences. Standard MRI uses the fact that hydrogen atoms behave differently in different tissue types to reconstruct anatomical images. Functional MRI uses sequences that are sensitive to blood water. Depending on whether it contains more or less oxygen, it has different magnetic properties that can be distinguished with MRI and we assume that more oxygenated blood flows to regions of higher activation. To pick up diffusion, two detection radiofrequency (RF) pulses are introduced shortly after each other which allows to see whether and where water has moved (Gazzaniga, Ivry & Mangun, 2008). Several different models can be applied to analyse and visualize the DI data subsequently. Diffusion Tensor Imaging (DTI) is the most common model. In the following section different models will be introduced, each of which tries to overcome different constraints and limitations.

### The Diffusion Tensor Model

In DI, one acquires many images that are diffusion weighted into different directions. So the MRI scanner uses RF pulse sequences tuned consecutively to diffusion into different directions, among them the three main directions x, y and z, but also directions in between. For DTI, diffusion information in optimally 60 or more directions is required and information from these differently weighted images is combined to calculate the so-called diffusion tensor, which is then used to reconstruct the DTI image. The diffusion tensor indicates how strong diffusion happens in each direction. The more spheric the tensor is the more water diffuses equally into all three directions while a more compressed tensor indicates directional dependency. Three quantitative measures can be reported for each voxel: The principal diffusion direction - the diffusion direction with the highest eigenvalue (Johansen-Berg & Rushworth, 2009), fractional anisotropy (FA) and mean diffusivity (MD). They indicate respectively local fibre orientation, the degree of directionality (FA) and the strength of the water diffusion (MD). FA describes thus the extent of anisotropy and ranges from zero (isotropic, e.g. in cerebrospinal fluid (CSF)) to one (completely anisotropic). Figure 1 nicely illustrates the relation between FA and the diffusion tensor. If the tensor is more spherical FA is lower because water diffuses with equal probabability into all directions (Johansen-Berg & Rushworth, 2009). FA is widely used its independence of local fibre orientation makes it a suitable measure to compare tract integrity across subjects (Smith et al., 2006).

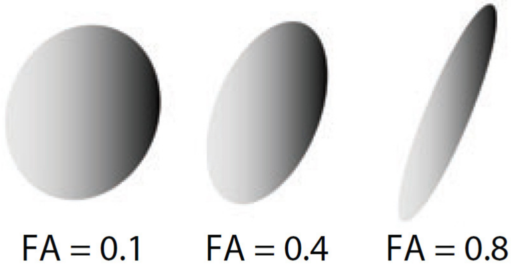

**Figure 1.** Relationship between diffusion tensor and FA values.
With permission from Johansen-Berg & Rushworth, 2009.

MD gives information about the strength of the diffusion in each voxel, regardless its directional dependency. For example, MD values are high in CSF but low in gray matter while FA values are low for both, since these regions typically show no strong directional dependent diffusion. With DTI data it is not possible to map several diffusion directions within one voxel because it only offers the principal diffusion direction. Notwithstanding, DTI is widely used and especially useful in regions with single fibre orientation where no crossings distort the results.

### Multiple Direction Approaches

Multiple direction approaches are advantageous because they are able to map intra-voxel diffusion heterogeneity. Compared to DTI, not only the principal diffusion direction but two or more directions of water diffusion are reported for each voxel. Further, the full diffusion tensor is used instead of only the principal direction in DTI. A drawback is that a much larger number of images from different angles is required, which increases scanning time (Hagmann et al., 2010). Examples are High Angular Resolution Diffusion Imaging (HARDI) or Diffusion Spectrum Imaging (DSI). They differ only slightly and for our purpose it is enough to say that they use different filters when analyzing the DI data (Wedeen et al., 2008).

Evidence for the ability of DSI to reconstruct tracts adequately comes from studies that used fixed monkey brains and compared the results of DSI and DTI (Wedeen et al., 2008) or autoradiographic tract-tracing (Schmahmann et al., 2007). Autoradiographic tract tracing allows to identify fibre tracts based on stained histological data. DSI resolution was lower than in the autoradiographic tract tracing, but fibres that crossed with an angle larger than 15° could be resolved (Schmahmann et al., 2007). Even in gray matter and subcortical nuclei, crossing fibres could be disentangled using DSI (Wedeen et al., 2008). Figure 2 illustrates the superiority of DSI (C) over DTI (D) in its ability to detect fibre pathways. Despite the fact that Schmahman et al. (2007) evaluated DSI using a fixed monkey brain instead of making in-vivo measurement, these results are promising for the technique in general. Notwithstanding, the main limitation of DSI is that it is very time consuming and expensive because of the large number of images that needs to be sampled (Wedeen et al., 2008; Hagmann et al., 2010). Also the longer scanning times increase the risk for noise introduced by patient movement.

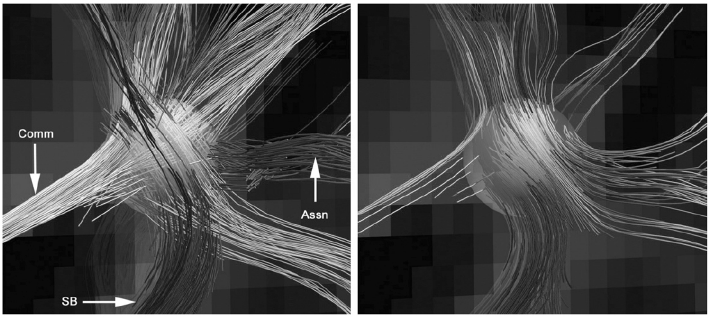

**Figure 2.** Comparison of DSI (C) and DTI (D) in mapping fibre pathways of a fixed monkey brain. With permission from Wedeen et al., 2008.

In sum, DTI is simple and straightforward in visualizing DW data and especially good for regions with single fibre orientations. Whereas multiple direction models are useful if a-priori knowledge suggests that the regions of interest (ROIs) contain a lot of touching (kissing) and crossing fibres that are hard to distinguish. Particularly, DSI has proven to be able to identify the same major pathways that were found with tracing methods (Schmahmann et al., 2007).

## FIBRE TRACKING

After a model has been fit, specific pathways can be identified with the help of fibre tracking algorithms during a process called tractography. The tractography reconstructs WM bundles either in a deterministic or in a probabilistic way.

### Deterministic versus Probabilistic

In Deterministic tracking a streamline is created along the principal diffusion direction starting from a seed ROI to identify the tract of interest (Hagmann et al., 2010). Extra information can be added to stop tracking, e.g. when FA, MD or the angle fall below a certain threshold. Figure 3 illustrates how the streamline runs along the tensors with the highest FA values.

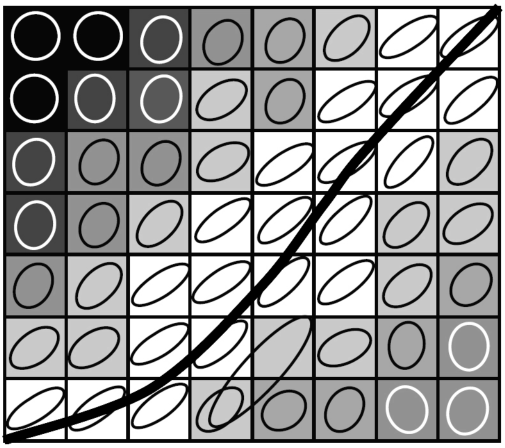

**Figure 3.** Simple Streamline Tractography. With permission from Johansen-Berg & Rushworth (2009).

Deterministic tracking thus gives for any particular seed the point of destination that is most likely. Especially in combination with a-priori knowledge about anatomic and functional ROIs, deterministic tractography provides good estimates of the neural connectivity.

On the other hand, probabilistic tracking focuses on the likelihood of anatomical connections between two points and offers a good way to overcome uncertainty (Wedeen et al., 2008). For any particular seed a 3D map of connectivity probability is given instead of only one terminal point (Roebroeck et al., 2008). This is done by sampling thousands of streamlines originating from the seed rather than one line along the principal direction. The criteria for creating these streamlines are similar to deterministic tractography in the sense that FA, MD and angular thresholds can be implemented, too. But while deterministic tractography allows only one connection from one voxel to the next, probabilistic tractography follows several possible streamlines at the same time if uncertainty arises about which tract to follow. The huge number of gathered streamlines is then analyzed and the density of lines reflects the probability of neural connections (Johansen-Berg & Rushworth, 2009). In addition, waypoints and exclusion points can help to limit the amount of identified tracts. Like the seed region, they need to be drawn manually. Waypoints are defined as points where every tract needs to run through, while exclusion masks define regions not to be included. A disadvantage of probabilistic tracking is that small levels of diffusion in different directions than along the axons will influence the analysis. This can require more smoothing and distort the results so that some fibre pathways are reconstructed inaccurately (Descoteaux, Deriche, Knösche & Anwander, 2009).

Conclusively, although probabilistic tracking requires longer calculation times, one advantage over deterministic tractography is that it allows to continue tracking if uncertainty arises, e.g. if tracts are really curvy (Johansen-Berg & Rushworth, 2009). Still, if hypotheses have been formed in advance deterministic tracking is superior to probabilistic tracking because it is more straightforward and does not show WM pathways in unexpected regions. Therefore, deterministic tracking should be preferred if knowledge and hypotheses about ROIs are available because then it provides more realistically reconstructed pathways.

### Comparing Groups

DI can also be used to compare WM structures between groups. There are two major approaches to do so. First, ROI approaches and tract-specific measurements only investigate group differences within the ROI, and therefore they require prior knowledge about the regions that are thought to differ (Catani, 2006). Secondly, whole brain Voxel Based Analysis (VBA) approaches allow group comparisons based on the entire brain volume. They have the advantage that they are fully automated and do not rely on a-priori assumptions. Further, it was found that VBA was able to identify more correlations with age than a ROI approach, which is probably caused by the averaging in ROI approaches (Snook, Plewes & Beaulieu, 2007).

If one group is found to have higher FA values this can have two different implications. Either it indicates a stronger connection strength, which holds especially in regions of unambiguous fibre pathways, or it indicates higher directional coherence in regions of fibre crossings (Rouw & Scholte, 2007). Tract statistics are one way to compare groups and it can be done in a deterministic way, for instance based on streamline tractography (Capalbo, 2008), or in a probabilistic way, as it is the case in tract based spatial statistics (TBSS). TBSS offers a whole brain voxel based approach and has many benefits – like reducing the amount of false positive connections caused by misalignment in other VBAs – but it also introduces problems, like rising the amount of false negatives because it only looks at the WM tracts that have been included in the analysis (Hsu et al., 2008). Some examples of comparing groups are discussed in the applications section of this paper.

## LIMITATIONS OF DIFFUSION IMAGING TECHNIQUES

### Technical and Methodological Constraints

Different models and fibre tracking algorithms have different technical and methodological constraints. One typical limitation is limited spatial resolution. While an axon bundle is estimated to have a diameter of about 1mm, the spatial resolution of DI lies approximately between 3 and 15mm$^3$, depending on the applied model (Descoteaux et al., 2008). Moreover, it is not yet clear where FA values actually are derived from. The reliability of FA values might be decreased by factors like large axon diameter. More importantly, when a signal is measured it is never sure what it actually reflects because there is no one-to-one relationship between FA and WM strength (Johansen-Berg & Rushworth, 2009). Fortunately, new tractography and registration methods are developing quite fast and at least problems like low resolution are being improved already. A study by Roebroeck and colleagues (2008) showed that heightened resolution can be reached by higher field strengths and this elevates the accuracy of DTI-based tractography since the principle diffusion directions would be described more accurately. However, higher field strengths introduces other problems like higher safety requirements or increased noise caused for instance by more susceptibility to magnetic materials, that might be contained among others in make-up. Furthermore, the human connectome project also aims at improving scanner technology and resolution (NIH Human Connectome Project, 2010).

### Fundamental Limitations

Nevertheless, other limitations of DI techniques are more fundamental in the sense that they are inherent to the method and cannot be improved as technology progresses. One is the lack of a gold standard where the results of different approaches can be compared to. Although data can be simulated using phantoms and compare the DI data thereto, this does not take into account imaging artefacts, limitations due to voxel size, and scanner noise (Campbell et al., 2005; Tournier et al., 2008). One study that presents a promising beginning for the validation process compared WM tracts of the rhesus monkey brain reconstructed with DSI to data derived by autoradiographic tract tracing. The result was promising and the main fibre tracts identified with DSI matched the findings from the histological investigation (Schmahmann et al., 2007).

Another fundamental limitation of DI is the kiss-crossing problem. Initially, it was mainly about the fact that DTI is not able to detect fibre crossings within single voxels. This challenged the interpretability of fibre tracts reconstructed with DTI, especially because it has been shown now that about one third of the voxels contains two different fibre orientations (Behrens, Johansen-Berg, Jbabdi, Rushworth & Woolrich, 2007). Today, HARDI techniques or multiple-direction models allow to address the crossing problem and identify orientation distribution functions (ODF), which are functions that describe several principal diffusion directions within a single voxel (Fritzsche, Laun, Meinzer & Stieltjes, 2010, Schmahmann et al., 2007). Still, it is only feasible to show that there is more than one orientation of water diffusion within a voxel, but not to distinguish between crossing fibres and fibres that are touching (“kissing”) each other (Tuch, 2004). Therefore, the fibre crossing problem was reformulated the kiss-crossing problem and this is what can still be called a fundamental limitation of DI.

Moreover, DI studies often rely on anatomical a-priori information to define seed ROIs and are only as good as the techniques used to gain the a-priori knowledge (Catani, 2006). Assuming a strong relationship between functional activity and connectivity as well, one can use functional rather than anatomical knowledge to determine the ROIs to investigate connections originating in the higher visual areas V5 and MT (Lanyon et al., 2009). They performed fMRI analysis to identify the functional ROIs before they performed deterministic tractography with the DI data. By taking functional information into account error induction due to interindividual differences can be reduced. Yet, it is important to bear in mind that there is no one to one relationship between functional activity and connectivity.

Finally, there is uncertainty about whether reconstructed fibre tracts are afferent or efferent, which can only be known by the use of tracers on the axonal level. Moreover, it can never be known with certainty whether there are connections present or not at all. A definite conclusion cannot be drawn by means of present DI studies since they measure connectivity only indirectly via water diffusion patterns (Johansen-Berg & Rushworth, 2009).

## APPLICATIONS

DI techniques offer the possibility for new research since it has been impossible to investigate WM pathways in vivo before. This section introduces current applications of DI, starting with the human connectome, which is an ambitious attempt to generate an exhaustive WM atlas.

### The Human Connectome

In 2009, the United States’ National Institute of Health (NIH) initiated the human connectome project with the goal to map the complete structural and functional neural connectivity of the human brain by multimodal scanning of 1200 brains of healthy adults. Such an atlas of WM tracts connecting brain regions could be useful in several fields of cognitive neuroscience. It would enable researchers to study relations between neural connectivity and neurological disorders in a novel way. The knowledge about structural and functional connections within and across individuals could be used to identify abnormalities linked to particular disorders, like Alzheimer’s or Schizophrenia, and this permits addressing those disorders from another direction. Nevertheless, identifying the connectivity patterns of the whole brain produces a great amount of data. The analysis of this data has to be done in a careful manner so that a large-scale model of the neural connectivity can be achieved. The process of structuring the data gained with DI in a manageable and convenient way poses a great challenge.

### Large-Scale Connectional Models

Large-scale connectional models are models of the fibre connectivity patterns in the human brain based on empirical findings and try to infer connectivity patterns of functionally subdivided brain regions (Catani, 2006). These models use ROI based approaches to identify networks that can be linked to functions. For instance, Capalbo (2008) mapped the structure of the human visual system by applying DTI to functionally relevant regions that had been identified a-priori. Evidence for the reliability of the reported large-scale model comes from agreements between subjects and congruence with a monkey connectivity matrix derived from tracing studies.

### Hodolocial Syndromes

When cognitive and behavioural dysfunctions can be related to hyper- or hypo-connectivity between certain brain regions rather than due to damage to the brain regions themselves, they can be called hodological disorders (termed by Catani, 2006). DI offers a tool to investigate underlying connection mechanisms and to detect pathological WM pathways (Catani, 2006). For instance, an increased risk for Alzheimer's has been found to be correlated with significantly different FA values in preclinical stages e.g. in the uncinate fasciculus (Taoka et al., 2006). Furthermore, attention deficit hyperactivity disorder (ADHD) (Silk, Vance, Rinehart, Bradshaw & Cunnington, 2009) and Huntington's disease (HD) (Reading et al., 2005; Weaver et al., 2009) have been associated with abnormal WM development. A whole brain voxel based approach was used to compare presymptomatic HD patients with a matched group of healthy controls. Presymptomatic HD patients could be identified by testing for a HD gene mutation. The results showed significantly decreased FA values in clusters of the frontal lobe for the pre-symptomatic subjects ($p<0.005$) (Reading et al., 2005).

### Verify WM Pathways Identified in Animal Studies

Human DI data can be compared to data of nonhuman primates that was gathered with invasive tract tracing like anterograde or retrograde tracing. Antero- and retrograde tract tracing offers information about whether connections are afferent or efferent. So we can transfer this knowledge about afferents or efferent tracts from animal studies to human DI data and circumvent this limitation of DI.

Further, Catani (2006) states that "verifying the existence of pathways described in animals and identifying possible tracts that are unique to humans belongs to the most essential purposes of DI" (p.3). A study that aimed at verifying findings of prior animal research was done by Leh, Ptito, Chakravarty & Strafella (2007). The researchers investigated cortico-striatal projections with probabilistic tractography and tried to find evidence for one of two hypotheses: While the information funneling hypothesis states that cortico-striatal projections are rather convergent, the parallel processing hypothesis claims that functionally distinct areas of the cortex have segregated projections to the striatum. They found that functionally related anatomical subdivisions of the striatum in humans projected to different cortical areas, which supports the information funneling hypothesis. Until then, this had only been investigated by animal studies and evidence was yielded by some fMRI and rTMS studies. Yet, measures of the structural connectivity can only be gathered with the help of DI.

### A link between WM structures and personality

Recently, correlations between WM structures and personality have been investigated. For instance, Cohen, Schoene- Bake, Elger & Weber (2009) explored whether personality traits are associated with WM integrity. Novelty seeking and reward dependence, which are generally linked to striatal activity have been measured with self-report questionnaires. Then, the DI images, acquired with HARDI, were aligned to a standard space to enable comparison. Indeed, connectivity maps of the striatum and scores on the questionnaires were linked. Statistical analysis revealed that high novelty seekers had stronger connecions from striatum to hippocampus and amygdala ($p< 0.05$) compared to high self-reported reward dependence, which in turn showed stronger connections between striatum and a distinct cortical network including areas in the orbitofrontal and prefrontal cortex (Cohen et al., 2009).

Until now it had not been possible to link personality to connectivity patterns. Especially in the field of behavioural and neuroeconomics where neural substrates of human decision making are investigated this offers new possibilities, like linking human decision making to structural connectivity patterns. In addition to personality traits, intelligence has been addressed by DI studies as well. Chiang and colleagues (2009) sampled FA values of twins and compared them to verbal, performance and full-scale intelligence quotients derived from the Multidimensional Aptitude Battery (MAB). The researchers aligned all diffusion images to a common space – similar to the TBSS procedure described earlier – in order to make the subjects comparable. They found a significant ($p < .05$) correlation of up to .4 between FA values and IQ scores – except for verbal IQ. Furthermore, Chiang and colleagues (2009) investigated heritability and found that the same genetic influences may affect both WM integrity and intelligence, which suggests a common underlying mechanism. This study is a good example of how DI can be used to offer new approaches to the study of intelligence and heritability.

### Experience Dependent WM Changes

DI has also been used to detect experience dependent changes in WM. For instance, one study investigated the effect of juggling on WM using DTI and TBSS (Scholz, Klein, Behrens & Johansen-Berg, 2009). TBSS enabled the researchers to perform a whole brain analysis and to compare WM integrity of the group before and after the juggling period. The results showed that six weeks of juggling training already led to significant WM changes, which did not occur in the control group.

The structural changes did not correlate with performance levels after training. Rather, they seem to reflect the time spent juggling. The study nicely illustrates that the combination of DTI and TBSS is not only useful in investigating changes between groups, but also in detecting changes within groups over time. Obviously, the results indicate that behaviour has influence on the neural pathways and the connectivity patterns in the brain. Since six weeks of training already induced WM changes one could suggest to access the effectiveness of therapy or medication with DI as well, e.g. in ADHD which has been linked to WM abnormalities (Silk et al., 2009). So, DI offers a good way to test to which extent behaviour and experience can change structural and functional connections in the brain.

### WM Changes with Age

DI studies have also addressed age related changes in WM. For instance, a whole brain approach revealed that several regions – e.g. the anterior corpus callosum – show a negative correlation between FA and age (Hsu et al., 2008). The choice for reporting FA values is based on the fact that FA is widely accepted to be good for intersubject comparisons. Their findings are consistent with other studies and suggest that fibre strength decreases with age (Thomas et al., 2008, Charlton, Schiavone, Barric, Morris & Markus, 2010). A DTI study investigated whether the age-related changes can be linked to cognition (Charlton et al., 2010). Indeed, they found a correlation between decreased working memory capacities and reduced WM integrity as indicated by MD. The fact that MD and not FA was found to correlate with working memory changes may be due to the fact that MD is a more global and homogenous measure of WM strength rather than directionality (Charlton et al., 2010).

Similarly, Thomas et al. (2008) investigated the relation between WM changes and age-dependent decreases in the ability to discriminate faces. The subjects had to judge whether two faces were the same or different. Accuracy – not RT – was then compared across the subjects ranging from twenty to ninety years of age and revealed that the ability to discriminate faces declined with age. Deterministic tracking of the inferior fronto-occipito fasciculus (IFOF) and the inferior longitudinal fasciculus (ILF), two regions associated with face recognition, revealed age-related declines of FA as well as a hemispheric asymmetry implying that the right IFOF is more affected by age than the left IFOF and the ILF. It has been suggested that the right occipito-temproal regions are crucial for face discrimination since damage to this region impairs this ability (Meadows, 1974). This finding supports the link between the right IFOF and the ability to discriminate faces. A positive correlation was also found between FA in the right IFOF and accuracy, meaning that lower FA values were associated with higher error rates (Thomas et al., 2008). All in all, these studies are consistent in showing that increased age goes together with decreased FA/MD and there is evidence for associations between cognitive functioning and WM integrity.

### Presurgical Planning

DI can also be used to identify specific pathways prior to brain surgeries. One of the pathways that have to be identified regularly is the optic radiation (OR), a WM bundle in the human visual system connecting the lateral geniculate nucleus (LGN) and the primary visual cortex (V1). The OR is of particular interest because it runs through the temporal lobe which is often dissected in epilepsy patients and its damage can lead to visual-field deficits. Further, the OR shows significant variability between subjects (e.g. Nilsson et al., 2007). This increases the need to identify it prior to surgery. Diffusion imaging is the first in-vivo method to identify the OR and measure distances to other anatomical landmarks. Linear regression analysis has shown that visual field deficits can be predicted by the distance between two landmarks of the OR, Meyer's loop and the temporal pole. This is good evidence for the effectiveness of presurgical tractography of the OR to decrease risk of visual field deficits (Yogarajah et al., 2009).

## DISCUSSION

The aim of this article was to introduce DI and to discuss advantages and disadvantages of the available models and algorithms. Subsequently, several applications have been addressed to show the importance and uniqueness of DI. The final question is whether the applications are useful and how DI can be used to improve further research. To start with, there are several reasons to assume that DI data is reliable. Support comes from the congruence between the DSI/DTI derived data and tracing studies in animals. Furthermore, the fact that DSI and DTI were able to detect major fibre pathways that have been found in animals before supports the reliability of DI even more (Schmahmann et al., 2007). Still, the question that arises is whether and when DI can be considered useful despite methodological and technical limitations.

In terms of the human connectome project, DI offers stunning possibilities. If the aim to improve methods and technology and to validate DI data is fulfilled, it may contribute to the further usefulness and reputation of DI. However, the amount of data to be collected is huge and good organization and visualisation techniques are required in order to benefit from it. Also in terms of large-scale connectional models promising possibilities arise. While Capalbo (2008) generated a functional model of the visual system, one of the best understood systems in the brain, future research might be able to address other sensory systems like audition or touch as soon as they are better understood. This might shed light on how senses are integrated and can have implications for the understanding of how we perceive the world around us.

Furthermore, DI provides a way to study causes of hodological syndromes. It is encouraging that different studies were able to find significantly different FA values in some frontal regions in presymptomatic HD patients compared to controls (Reading et al., 2005, Weaver et al., 2009). Although it is not yet clear what those FA changes actually reflect, the value of this application lies in the fact that DI might eventually contribute by identifying illnesses before other diagnostic tools are able to do so. We do not yet know whether FA changes precede other changes associated with specific diseases, like cell death. Yet, it is worth to investigate this, since this would make DI a useful and new diagnostic tool in the future.

The verification of neural pathways that have been found with tracing in animal studies can test hypotheses about brain circuits that have only been based on animal research before. Leh et al. (2007) found evidence for a hypothesis about cortico-striatal projections by using probabilistic tractography. The choice for probabilistic tracking can be explained by the fact that the researchers did not want to constrain the tractography by using deterministic tracking and a-priori information that could have influenced in favour of one of the two hypotheses. This is another example of how the pro's and con's of the different methods and algorithms have to be balanced in order to guarantee a useful DI application. Personality has also been investigated with the help of DI and deterministic tracking and the technique has proven to be useful as it allowed researchers to correlate FA values and personality traits (e.g. Cohen et al., 2009).

Finally, DI experiments were able to show that experience and ageing influence WM structure as well. For instance, in the juggling study behaviour shaped WM (Scholz et al., 2009). The fact that DI is able to investigate behaviour induced WM changes leads to possible future applications like to investigate whether WM abnormalities decrease or even vanish in ADHD children as a result of reduction of the symptoms after therapy or medication. Finally, apart from research related applications, DI has also proven to be a useful tool in the clinical routine. Tractography in presurgical planning can be used to identify structures that are at risk of being damaged.

For the future, DI might be of use in lesion studies, which try to link cognitive or behavioural deficits to specific brain damages and therewith aim to find out whether an area is necessary for a particular function. A frequently encountered problem in lesion studies is that an investigation with functional magnetic resonance imaging (fMRI) only measures whether a region is intact or not. If the region is active and there is a cognitive or behavioural deficit, the region is not assumed to be necessary for this particular function, but it might be that this region is disconnected from other regions it usually interacts with. So it would still be linked to the observed deficit. Therefore, it would be valuable to combine lesion studies with DI techniques in the future, to get a more complete picture.

To sum up, DI has proven to be a useful tool in the cognitive neurosciences. Its benefits lie not only in its ability to reconstruct WM pathways in vivo, but also in the new methodologies that allow us to compare WM structure between groups or within groups over time. Furthermore, research also offers more and more evidence for DI's reliability, like the congruence between tracing and DSI when studying monkey brains. Even if there remain several limitations like the lack of a gold standard or the kiss-crossing problem the advantages outperform these limitations in most cases. The vagueness with regard to the exact meaning of FA also needs to be addressed in more detail in the future since FA is widely used for statistical comparisons. Yet, for current purposes DI provides useful new insights and methods are improving so that limitations like not being able to detect intravoxel diffusion heterogeneity soon will not be a problem anymore. Therefore it can be concluded that DI offers useful and more and more reliable results if the right methods and algorithm are chosen.

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RODERICK BRONZWAER

# False memories and subsequent false testimonies

Review

In this review paper, an introduction to the concept of false memories is given and subsequently compared with the current state of affairs in the research on modern juridical deception. This covers the most widely-used techniques in the area of lie-detection: The Comparison Question Technique and the Guilty Knowledge Test. It then attempts to connect any cross-compatibility to the area of false testimonies and to give an explanation as to why and how this is the case. It is concluded that, in spite of a considerable amount of research, the knowledge that has been acquired over the course of decades is not yet sufficient to be adequately applied in the field, and that accurate detection of false testimonies through techniques resembling above-mentioned may be decades away.

**Keywords**: Guilty Knowledge Test, Comparison Question Technique, psycho-physiological lie detection, false memories, false testimonies

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## THE WORLD OF FALSE MEMORIES

False memories have been the subject of a wide variety of research in the past few decades. It has become clear that the events which we experience every day are not stored in the form of a concrete icon in a museum that heralds our collective memories. Instead, it appears that there is a substantial difference between reconstructing and reproducing memories. For the purpose of clarification, reconstructive memory refers to the active process of filling in missing elements whilst remembering, there where reproductive memory refers to an accurate production of material from memory. The former results in errors more frequently. This subtle yet crucial difference can make or break a person's conviction when tried in court, with all sorts of implications resulting. To quote Loftus (1997): "If we cannot believe our own memories, how can we know whether the memories of a victim or a witness are accurate?". Questions to be posed around these conundrums may be "How can we distinguish between false and true memories?", "Can we even analyze the difference with accuracy when our methodology is also based on said memory?", or "Are possible remedies against false confessions plausible for use in court by means of a formula or technique?". Studies show that even trained memorizers (i.e. undergraduates) can unjustifiably recall critical lures that were not actually presented but only relevant to associated words, mere seconds after memorizing a list of words. A possibly more relevant part, as demonstrated in research on the influence of "remembering" versus "knowing", that merely associating words with a more general term can cause people to actually remember a word that was not shown at all. In fact, when asked, those same people recall the word being memorized. They did not simply say that they remember it, but have an active recollection of when they saw it (Roediger, & McDermott, 1995).

There are numerous cases, especially in American history, in which suspects are wrongfully sentenced to prison due to twisted or even plain false testimonies by witnesses. These false testimonies are rarely on purpose, but reflect that deficiencies in our retrieval of memory can lead to dire consequences, and in some cases even death. A factor that may well be very influential for false memories is the distinction between reproductive and reconstructive memory. However, in the above-mentioned study, it is demonstrated that false recollections of words can have the same frequency of occurrence as the memory of words that actually did show up around the middle of a wordlist during a memorization test. This underlines the fact that the "accurate production of material" as seen in reproductive memory can be mistaken for material that is in fact constructed. Keeping a close eye on the advancements made in this study, it is argued that there may one day be a successful bridge, closing the gap between contrived laboratory experiments and practice in the field, specifically the justice system. However, more research is deemed necessary for any speculation to come within grasp. This leads us to our research question: "Can the detection of false memories be transferred and accurately used to combat false testimonies and the masking of guilty knowledge in the justice system?"

## THE DETECTION OF JURIDICAL DECEPTION AS WE KNOW IT

In an applied juridical context, there are several interrogation techniques that rely on either a polygraph or other means of psycho-physiological detection (Saxe, Dougherty, & Cross, 1985). The first one is the Control / Comparison Question (Polygraph) Technique, or CQT. It is the most widely used technique involving a polygraph in the field of criminal investigations, yet it is tainted by criticism. In short, it is a technique applied in several distinct stages. Interpreting the explanation given by Elaan (2003): "First, the examinator becomes familiar with the details of the investigated crime by receiving written reports and by speaking with the interrogator who is familiar with the case and ordered they polygraph test", the first stage's purpose is to acquire relevant background information, but at the same time begins to raise questions regarding it's own validity, as it is chiefly governed by a distinct subjective nature. Elaan (2003) follows: "Then, the examiner invites the subject into the examination room and starts an extensive pre-test interview in which the examinee is given the opportunity to present his or her (own) version of the case". Again, the objectivity, the purpose of the test, is far to be seen. However, this touch of subjectivity allows the examiner to formulate the questions that will be used in the test itself. Next, a consent form is signed, and the actual examination begins. The subject is attached to a polygraph and 3 distinct types of questions are presented; relevant questions, control questions, and irrelevant questions. The general feature that is measured using the CQT is the pattern of physiological response. Innocent subjects should be wearier of control questions, which are often broad and can be difficult to respond to truthfully, there where guilty subjects should be wearier of the relevant questions of which they know they must lie to. Over the years, the biggest criticism uttered on this test is one of weighing. As for a hypothetical guilty subject, the polygraph test is but one of an entire array of investigative techniques used to assess his or her guilt, and a subjective assessment of the importance of a polygraph test can gravely influence the physiological response to relevant questions (Ben-Shakar & Furedy, 1990).

The second one is the Guilty Knowledge Test, or GKT. It is a test relying on a psycho-physiological method to identify subjects carrying concealed information regarding a crime. On a basic level, the test consists out of multiple choice questions, some of which are directly related to the crime in question. To quote MacLaren (2001): "The test allows the examiner to detect concealed knowledge by observing the occurrence of involuntary physiological responses that are temporally related to the presentation of correct answers". The GKT is deemed to be a very valid method to distinguish guilty from innocent subjects (Ben-Shakar & Furedy, 1990). However, part of the studies that focus on the validity of GKT were conducted by researchers having a generally bad disposition on the 'competing' CQT (Lykken, 1960). Another issue regarding the validity of the studies on GKT is the lack of field research backing up GKT (Elaad, Ginton, & Jungman, 1992). The former study however attempted to conduct something close to field research by sampling examinees on the basis of polygraph records (acquired through the Israel Police Scientific Interrogation Unit) that belonged either to verified deceptive examinees, or innocent examinees. Even though this cannot be considered field research, it does give a more-or-less solid ground for verifying the effectiveness of the GKT. The study showed that by making use of the GKT, examiners could place examinees in pre-determined categories (e.g. Guilty Knowledge Indicated, or No Guilty Knowledge Indicated) with significant accuracy. However, it was also noted that several factors should be taken into consideration when interpreting the results of the GKT, namely the time passed between the crime and the test, the examinee's interest in the content of the questions, the active acquisition of the relevant information, and the interference of the relevant information. The latter two reflect the influence that false memories can have on results. This is an important piece of the puzzle, as it may open the gateway that allows us to connect the fields of lie-detection and false testimonies, or in broader terms, to connect contrived application to field application.

## CROSS-COMPATIBILITY, AND THE CURRENT CONCLUSION

The purpose of the vast explanation of techniques described above is to sketch the state of which research regarding false testimonies is currently in. Even though these techniques are but a part of some juridical processes, they reflect the underlying issues at hand. Most false memory and false testimony research is done in a contrived setting, and their external validity leaves much to be desired. Furthermore, individual differences seem to play a rather big role. This can be induced from the great differences in success-rates between studies themselves.

This leads us to the current conclusion. At this time, there is a considerable amount of research going on in not only the area of false memories and false testimonies, but also in that of lie-detection itself. However, for the time being, more research should be conducted in order to make any claims towards identifying false testimonies in court. As the research that has already been done spans a period of decades, it is an unfortunate estimate that the true application will take more decades. As the detection of guilty knowledge and general lies are coming more and more within grasp, the detection of 'not-guilty' guilty knowledge has barely been unveiled.

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NICOLAI GROEGER

# Meta Needs in the context of Schema Therapy: Psychometric qualities of a new Meta Needs Questionnaire and relationships with depression, anxiety and schemas

ORIGINAL PAPER

Schema Therapy proposes that when core emotional needs are frustrated in childhood, these experiences lead to rigid patterns of thoughts and feelings in important life circumstances, that are known as early maladaptive schemas (Young et al., 2003). Clinical practice recently indicated another type of needs that is more abstract and philosophical, similar to the ones proposed by existential and humanistic psychology. “Meaning in life”, “living an authentic life”, and “feeling as a part of the world” are some examples (Prochaska & Norcross, 2010), which are also called “Meta Needs” (Maslow, 1971). To provide the groundwork for utilizing the Meta Needs concept in the Schema Therapy practice, a Meta Needs Questionnaire (MNQ) was developed that investigates the satisfaction levels of Meta Needs. The present study explores the psychometric properties of the MNQ. Factor analysis of the items revealed two factors, which were labeled “Authenticity and “Liveliness”. Item-analysis showed good to excellent reliability measures of the MNQ, also regarding split-half reliability. Correlations with anxiety and depression were significant, demonstrating construct validity of the scale. As to criterion-related validity, the study confirmed the hypothesis that schemas negatively correlate with attained Meta Needs fulfillment. A possible interpretation of the results is that when core emotional needs are unmet, Meta Needs are also not met, and this state seems to be related to clinical symptoms..

**Keywords:** Meta Needs; Schema Therapy; Upward Arrow technique; Maslow; existentialism

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## INTRODUCTION

Schema Therapy proposes that people can develop negative schemas (beliefs about the self and the world) in childhood when their emotional core needs are frustrated. These needs are *realistic limits and self-control, secure attachments, autonomy, spontaneity and play, and freedom to express valid needs and emotions* (Young, Klosko, & Weishaar, 2003). When these core-needs are intensely violated or unmet in childhood, the child learns from these negative experiences something about the environment, other people and the self. More precise, the corresponding memories, emotions, thoughts and sensations of the body are organized into a broad pattern of negative experience that can become rigid and persistent through life, depending on many factors such as the child's vulnerability to these experiences, their intensity and duration. Such a rigid pattern is called early maladaptive schema (from now on referred to as "schema"). When activated by circumstances later in life, schemas trigger emotions, cognitions and behaviors. These were formed as a reaction to the early life experiences which created the schema, and are not functional for meeting a person's needs in later adult life (Young et al., 2003). Up till now, 18 schemas have been identified. They are grouped under five domains. Each schema domain corresponds to one of the five core emotional needs. When a core emotional need is neglected, the person may develop one of the schemas from the corresponding domain, but not schemas belonging to one of the other domains. The schema concept can thus be said to rest on the assumption that five core emotional needs are crucial for psychological health. Their neglect leads to schemas that are often at the root of chronic Axis I and Axis II disorders (Rafaeli, Bernstein, & Young, 2011).
Another, more existential and abstract class of needs, termed "Meta Needs" by Abraham Maslow (1971), has been mentioned in other psychotherapy systems. Existential psychotherapy recognizes the need for *meaning in life and death*, which is to find the own existence meaningful, including the certainty that our lives will end. Another need is to live an authentic life, that can be described as a prerequisite to face all parts of reality directly without hiding from it (Prochaska & Norcross, 2010). Carl Rogers (1961) also describes how person-centered therapy leads to *vividness, greater joy and excitement in life.*

The concept of Meta Needs and their link to clinical symptoms has never been studied empirically. No attempts have been made to investigate their potential relationship with early maladaptive schemas and core emotional needs of the Schema Therapy framework. However Maslow (1971) proposed that Meta Needs are related to more basic needs, and are important for psychological health. To investigate this concept, a Meta Needs Questionnaire (MNQ) was developed by A. H. Karaosmanoğlu that has not been published elsewhere yet. The MNQ is a self-report scale that assesses to what degree Meta Needs are met. Each item is a statement about the fulfillment of a Meta Need. The items were obtained from clinical observations of patients with a diversity of symptoms and diagnoses. Due to the nature of this procedure, it was hypothesized that some items of the MNQ would be redundant, and that groups of items would be different expressions of essentially a much smaller set of variables, i. e. measuring the same Meta Needs. Therefore factor analysis was used to explore the item structure.

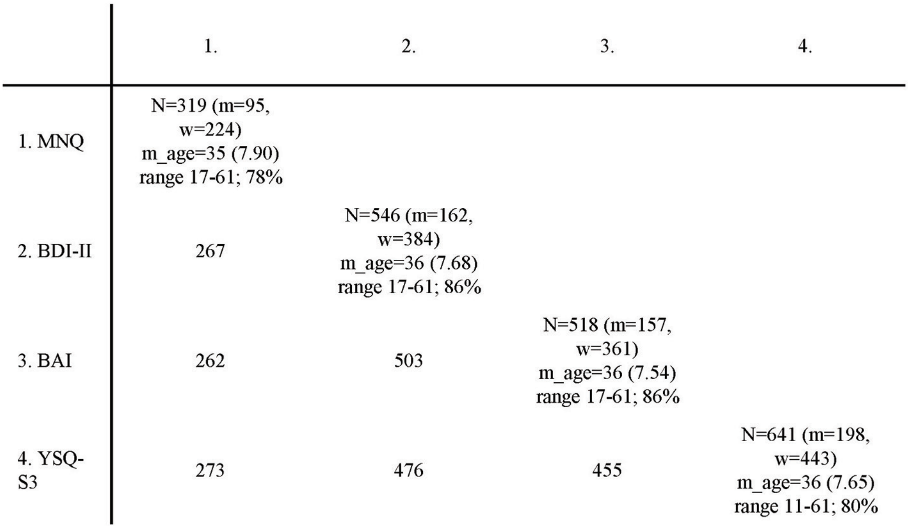
Concerning that negative schemas trigger intense negative emotions, distort the perception of reality, and have a negative impact on interpersonal relationships (Young et al., 2003), it seems likely that they would conflict with aforementioned Meta Needs. It was therefore hypothesized that people who have strong schemas, as indicated by high scores on the YSQ-S3, tend to experience less Meta Need fulfillment, as indicated by lower scores on the MNQ. Thus the two measures should negatively correlate. Moreover, according to Existential Psychotherapy, when Meta Needs are unfulfilled, pathologies like *existential anxiety* and *existential guilt* may arise (Prochaska & Norcross, 2010). In addition, Maslow (1971) states that frustration of Meta Needs is linked to psychological problems, crises and symptoms. Therefore it was also hypothesized that Meta Needs fulfillment (indicated by the MNQ total score) negatively correlates with clinical symptoms such as depression and anxiety, and therefore with the BDI-II and BAI total score. The former hypothesis serves to verify criterion-related validity, the second one construct validity of the MNQ. In addition reliability of the new questionnaire was assessed with an item-analysis.

## METHODS

### Participants

The study is based on data from the PsikoNET database. Since 2003 patients have been using the PsikoNET web-based interface to fill in several questionnaires. Diagnostic assessment of the patients was conducted by a psychiatrist. Approximately 30% of the participants were diagnosed with an anxiety disorder or depression. The remaining participants did not meet any diagnostic criteria and primarily had interpersonal relationship problems. Completing the questionnaires was part of a Schema Therapy intervention. The questionnaires were completed simultaneously; hence the design of this study is cross-sectional. Most participants did not fill in all the questionnaires that were used in this study; therefore N varies across combinations of tests. Table 1 shows the amount of participants in all applied combinations, men-women distribution, mean age with standard deviation, age-range, and percentage of participants who answered the question about their gender.

**Table 1** Properties of the sample of participants per combination of psychometric tests



| | 1. | 2. | 3. | 4. |
|---|---|---|---|---|
| 1. MNQ | N=319 (m=95, w=224)<br>m_age=35 (7.90)<br>range 17-61; 78% | | | |
| 2. BDI-II | 267 | N=546 (m=162, w=384)<br>m_age=36 (7.68)<br>range 17-61; 86% | | |
| 3. BAI | 262 | 503 | N=518 (m=157, w=361)<br>m_age=36 (7.54)<br>range 17-61; 86% | |
| 4. YSQ-S3 | 273 | 476 | 455 | N=641 (m=198, w=443)<br>m_age=36 (7.65)<br>range 11-61; 80% |

*Note:* The diagonal gives information about each test. The off-diagonals show the amount of participants per combination of tests.

*Abbreviations*: N=amount of participants who filled in the questionnaire, w=amount of women, m=amount of men, m_age=mean age (with standard deviation) range=range of ages and percentage % of participants who reported their age; MNQ=Turkish Meta Needs Questionnaire, BDI-II=Turkish Beck Depression Inventory-II, BAI = Turkish Beck Anxiety Inventory, YSQ-S3=Turkish Young Schema Questionnaire – Short form-3

## Materials

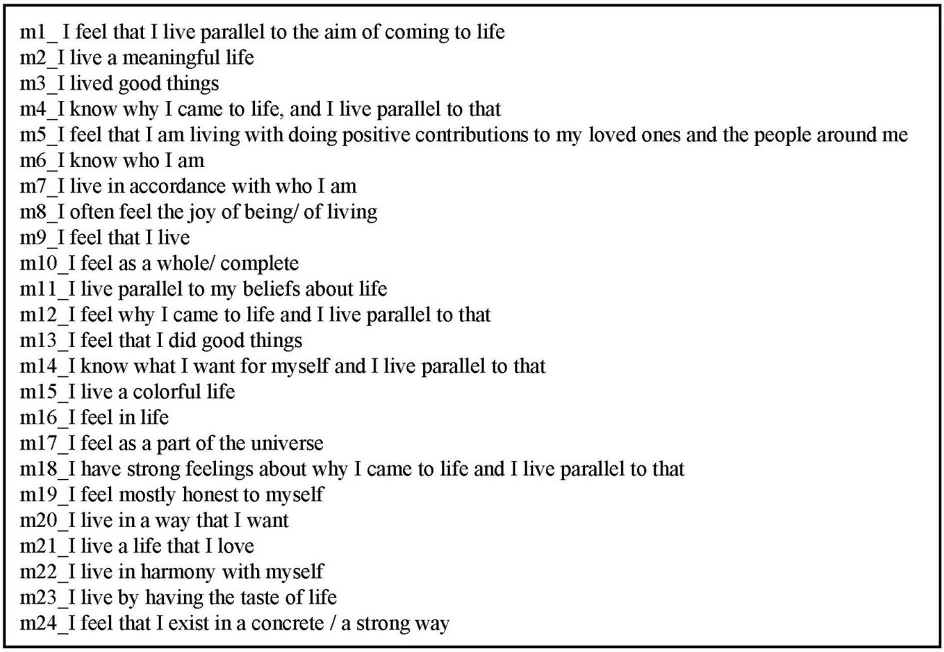
### *Meta Needs*

*Upward arrow technique.* Twelve years ago, the 'upward arrow technique' was developed by A. H. Karaosmanoğlu (personal communication, September, 2011). This technique can be understood as the counterpart to the downward arrow technique, originally developed by Beck (1995). When the downward arrow technique is used, a therapist asks a series of open-ended questions, to uncover the negative meaning that underlie the automatic thoughts of a patient. Negative core beliefs and attitudes can be exposed with this technique. The upward arrow technique works in the opposite direction. By asking a series of questions about the positive function of a dysfunction, several layers of meaning and functionality, which the dysfunction has for the patient, are revealed. These layers consist of increasingly broader and more abstract concepts of life fulfillment. 'Meta Needs' was chosen as a term for the broadest and most abstract pattern that can be found at the core level with this technique, because of the striking similarities with Meta Needs as proposed by Maslow (1971) and Existential Psychotherapy (Prochaska & Norcross, 2010). In summary, with the upward arrow technique the link between a dysfunction and Meta Needs can be uncovered, which is, the behavior acts as a maladaptive attempt to fulfill the patient's Meta Need(s), an idea that was originally proposed by Maslow (1971).

*Meta Needs Questionnaire (MNQ).* The 24 items of the MNQ were derived from clinical practice. They are essentially reformulations of the answers that patients gave when the upwards arrow technique was used. Each item is a positive statement about the fulfillment of a Meta Need, rated by the participants on a six point Likert scale, according to how well the statements describe them (range 1= "completely untrue of me" to 6="describes me perfectly").

Figure 1 shows the items. They were originally framed in Turkish, and the participants of the present study used the original Turkish version of the MNQ. The items were translated so that non-Turkish readers can understand them. Although we translated the items carefully, the actual analysis is based on the Turkish scale, and may or may not deviate from findings that would have been obtained if the English version had been used. Furthermore the English version is not an official translation of the Turkish MNQ, since the necessary procedures to translate a psychometric scale (van de Vijver & Hambleton, 1996) were not applied. Please regard the translated scale only as a support to understand the content of the items.

**Figure 1** English translation of the Meta Needs Questionnaire (MNQ)



m1_ I feel that I live parallel to the aim of coming to life
m2_I live a meaningful life
m3_I lived good things
m4_I know why I came to life, and I live parallel to that
m5_I feel that I am living with doing positive contributions to my loved ones and the people around me
m6_I know who I am
m7_I live in accordance with who I am
m8_I often feel the joy of being/ of living
m9_I feel that I live
m10_I feel as a whole/ complete
m11_I live parallel to my beliefs about life
m12_I feel why I came to life and I live parallel to that
m13_I feel that I did good things
m14_I know what I want for myself and I live parallel to that
m15_I live a colorful life
m16_I feel in life
m17_I feel as a part of the universe
m18_I have strong feelings about why I came to life and I live parallel to that
m19_I feel mostly honest to myself
m20_I live in a way that I want
m21_I live a life that I love
m22_I live in harmony with myself
m23_I live by having the taste of life
m24_I feel that I exist in a concrete / a strong way

*Note:* Please note that this is not an official translation of the Turkish MNQ which was used in the study. The MNQ was developed by Karaosmanoğlu in 2012 and has not been published elsewhere yet.

### *Schemas*

*Turkish Young Schema Questionnaire - Short form-3 (YSQ-S3).* The Turkish version is a translation of the English YSQ-S3, which is a 90-item self-report questionnaire, measuring 18 early maladaptive schemas. Participants were asked to rate the items in terms of how they feel about their lives. Items were scored on a 6-point Likert scale (range: 1 completely untrue – 6 describes me perfectly). In a previous study, acceptable validity and reliability measures were found in a Turkish sample (Soygüt, Karaosmanoğlu, & Çakır, 2009).

### *Symptom information*

*Turkish Beck Depression Inventory-II (BDI-II).* The BDI-II is a well accepted 21-item self-report questionnaire assessing how the patient has been feeling during the last two weeks, with high internal consistency (Beck, Steer, Ball, & Ranieri, 1996), good validity and test-retest measures (Beck, Steer, & Brown, 1996). It measures the affective, motivational, physiological, and cognitive symptoms of depression. Items are rated from 0 (absence of symptom) to 3 (severe symptom). In a previous study the Turkish translation was found to have good psychometric properties, furthermore the cut-off scores were found to be applicable for the Turkish culture (Kapci, 2008).

*Turkish Beck Anxiety inventory (BAI).* The BAI contains twenty-one items about how the patient has been feeling during the last week with regard to symptoms of anxiety, especially cognitive and somatic aspects. Items range from 0 (absence of symptom) to 3 (severe symptom). The BAI is widely used and has good psychometric qualities (Fydrich, Dowdall, & Chambless, 1992). More importantly, the Turkish version of the BAI was found to have high internal consistency and good validity measures (Ulusoy, Sahin, & Erkmen, 1998).

## **Statistical analysis**

### *Factor analysis and item exclusion*

The sample of 319 patients who completed the MNQ was factor-analyzed. Items which had similar loadings on the factors were then removed and the next factor analysis was conducted. Again, those items with similar loadings were excluded from analysis. The procedure was continued until only items were left that showed differences in the factor loadings of at least 0.1. Items were then assigned to the factors according to their loadings. The factors were given labels that are representative for the encompassing items.

### *Reliability*

To determine the internal consistency, a reliability analysis was conducted with the items that had not been excluded in the previous step, first for the whole scale, then the two factor-subscales separately. In addition the split-half reliability was tested for each factor-subscale.

### *Validity*

To test the criterion-related validity of the MNQ, it was correlated with the BDI-II, and BAI. To examine construct validity, a correlation analysis of the MNQ with the YSQ-S3 was conducted.

## RESULTS

### Factor analysis

An exploratory factor analysis was carried out, using the principal components method, with varimax rotation. The orthogonal rotation method was chosen, in order to obtain uncorrelated factors. The data were found adequate for principal component analysis (KMO = .96). The Kaiser Criterion indicated a two-factor structure with an eigenvalue of 1.20 for the second component, which explained 4.99% of the variance. The scree plot test however suggested a one-factor solution.

Examination of the residual correlation matrices revealed that only 26% of the residuals had values greater than 0.05 for the more favorable two-factor solution, compared to 36% when one factor was extracted. The Maximum Likelihood Goodness-of-fit Test was significant (p<.01) in both the one-factor ($\chi^2$=1237.94, df=252) and the two-factor model ($\chi^2$=857.48, df=229). Theoretically more than one factor was expected, concerning that previous literature suggested more than one Meta Need (Maslow, 1971; Prochaska & Norcross, 2010). The content of the items appeared to be strongly heterogeneous, so it was considered unlikely that they were parallel expressions of a single latent variable. Furthermore, several items were judged seemingly similar to each other. The alternative explanation for the one-factor model, that each of the 24 items represents a unique Meta Need, was therefore not considered reasonable either. It should be noted that the latter examinations were not based on objective criteria. Taken together the findings were interpreted in favor of the two-factor model.

After rotation, a total of 65.08 percent of the variance could be explained by the two factors (33.15% and 31.93%, respectively). Four items with highly similar content were identified *(m1_I feel that I live parallel to the aim of coming to life; m4_I know why I came to life, and I live parallel to that; m12_I feel why I came to life and I live parallel to that, m18_I have strong feelings about why I came to life and I live parallel to that)*. In order to reduce redundancy and to distinguish the factors more clearly, three items were excluded, and only m4 which had the highest loading on one of the factors among the four, as well as the biggest difference in loadings on the factors, was retained. The next factor analysis was carried out with the remaining items. Items with a difference in factor loadings less than 0.1 after rotation (m2, m10, m14) were removed. For the same reason, m24, and afterwards m13 were excluded in the next two iterations. Table 2 shows the process of item exclusion and the factor loadings for the five successive factor analyses. The 16 items of the last iteration fulfilled the criterion and were assigned to a factor, according to their loadings after varimax rotation. Finally, based on the content of the items, especially those with very high and unambiguous loadings, the first component was labeled “Liveliness” (LN), and the second “Authenticity” (AU). Table 3 shows the two resulting factors.

**Table 2** The two extracted factors, items and factor loadings

| Liveliness (LN) | | Authenticity (AU) | |
|---|---|---|---|
| factor loading | item | factor loading | item |
| .85 (.33) | m23_I live by having the taste of life | .82 (.24) | m6_I know who I am |
| .81 (.17) | m15_I live a colorful life | .77 (.35) | m7_I live in accordance with who I am |
| .80 (.31) | m8_I often feel the joy of being/ of living | .68 (.19) | m19_I feel mostly honest to myself |
| .78 (.40) | m16_I feel in life | .68 (.49) | m11_I live parallel to my beliefs about life |
| .76 (.33) | m20_I live in a way that I want | .64 (.40) | m5_I feel that I am living with doing positive contributions to my loved ones and the people around me |
| .75 (.42) | m21_I live a life that I love | .63 (.46) | m4_ I know why I came to life, and I live parallel to that |
| .73 (.41) | m9_I feel that I live | | |
| .66 (.53) | m22_I live in harmony with myself | | |
| .62 (.43) | m17_I feel as a part of the universe | | |
| .50 (.32) | m3_I lived good things | | |

*Note:* Items with higher loadings were given more attention when the factors were labeled. The first items in the list are thus most representative for the names “Liveliness” and “Authenticity”. The number in brackets shows the loading that the item has on the other factor.

**Table 3** Rotated component matrices and item exclusions for a series of factor analyses

| | | 24 items | | 21 items | | 18 items | | 17 items | | 16 items | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | AU | LN | LN | AU | LN | AU | LN | AU | LN | AU |
| m1 | I feel that I live parallel to the aim of coming to life (excluded before 21 item analysis) | .76 | .32 | | | | | | | | |
| m2 | I live a meaningful life (excluded before 18 item analysis) | .70 | .51 | .59 | .61 | | | | | | |
| m3 | I lived good things | .27 | .52 | .50 | .30 | .50 | .31 | .50 | .31 | .50 | .32 |
| m4 | I know why I came to life, and I live parallel to that | .81 | .30 | .44 | .66 | .46 | .62 | .46 | .63 | .46 | .63 |
| m5 | I feel that I am living with doing positive contributions to my loved ones and the people around me | .63 | .38 | .39 | .64 | .40 | .64 | .41 | .65 | .40 | .64 |
| m6 | I know who I am | .74 | .26 | .23 | .83 | .24 | .83 | .24 | .82 | .24 | .82 |
| m7 | I live in accordance with who I am | .73 | .32 | .33 | .76 | .35 | .76 | .35 | .76 | .35 | .77 |
| m8 | I often feel the joy of being/ of living | .38 | .76 | .79 | .32 | .80 | .32 | .80 | .32 | .80 | .31 |
| m9 | I feel that I live | .43 | .72 | .72 | .42 | .73 | .42 | .73 | .41 | .73 | .41 |
| m10 | I feel as a whole/ complete (excluded before 18 item analysis) | .60 | .53 | .57 | .57 | | | | | | |
| m11 | I live parallel to my beliefs about life | .69 | .45 | .47 | .69 | .49 | .68 | .49 | .68 | .49 | .68 |
| m12 | I feel why I came to life and I live parallel to that (excluded before 21 item analysis) | .76 | .45 | | | | | | | | |
| m13 | I feel that I did good things (excluded before 16 item analysis) | .57 | .49 | .55 | .52 | .56 | .49 | .57 | .50 | | |
| m14 | I know what I want for myself and I live parallel to that (excluded before 18 item analysis) | .63 | .50 | .56 | .57 | | | | | | |
| m15 | I live a colorful life | .21 | .80 | .81 | .16 | .80 | .20 | .81 | .17 | .81 | .17 |
| m16 | I feel in life | .43 | .78 | .78 | .41 | .78 | .41 | .78 | .40 | .78 | .40 |
| m17 | I feel as a part of the universe | .37 | .68 | .63 | .43 | .62 | .44 | .62 | .43 | .62 | .43 |
| m18 | I have strong feelings about why I came to life and I live parallel to that (excluded before 21 item analysis) | .69 | .43 | | | | | | | | |
| m19 | I feel mostly honest to myself | .49 | .30 | .19 | .65 | .19 | .68 | .19 | .67 | .19 | .68 |
| m20 | I live in a way that I want | .45 | .67 | .75 | .35 | .76 | .32 | .76 | .33 | .76 | .33 |
| m21 | I live a life that I love | .53 | .67 | .73 | .44 | .75 | .42 | .75 | .42 | .75 | .42 |
| m22 | I live in harmony with myself | .55 | .64 | .65 | .55 | .66 | .53 | .66 | .53 | .66 | .53 |
| m23 | I live by having the taste of life | .39 | .82 | .84 | .34 | .84 | .33 | .84 | .33 | .85 | .33 |
| m24 | I feel that I exist in a concrete / a strong way (excluded before 17 item analysis) | .45 | .63 | .58 | .51 | .58 | .53 | | | | |

*Note:* The coefficients are factor loadings for the two factors Liveliness (LN) and Authenticity (AU). The highlighted items had similar loadings on both factors (difference < .1), and were excluded from subsequent analyses.

## Reliability

First an item analysis for the reduced 16-item Meta Needs Questionnaire was conducted, then the sub-scales were examined separately. Cronbach`s alpha was $\alpha = .95$ and item total correlations were generally high (range .54-.83, mean = .73). Cronbach´s alpha for the 10-item LN sub-scale was $\alpha = 0.95$ and item total correlations were high (range .53-.85, mean = .77). For the 6-item AU sub-scale Cronbach´s alpha was $\alpha = 0.88$ and item total correlations were high (range .55-.76, mean = .69). In none of the three analyses any items had to be removed, since the biggest possible gain in Cronbach´s alpha if item deleted, in all the analyses, was negligible (+.004).

To assess split-half reliability the adjusted Spearman-Brown formula was used: $\mathbf{r_{sb} = 2r_{xy} / (1+r)}$ where $r_{sb}$ represents the split-half reliability coefficient, and $r_{xy}$ the correlation between the two halves of the sub-scale. I randomly split the *Liveliness* sub-scale in two halves by assigning the three items with the highest index *(m21, m22, m23)* and the two with the lowest *(m3, m8)* to the *first half*. The *other half* consisted of items *m9, m15, m16, m17, and m20*. The correlation was r=.90, p<.01), and reliability was $r_{sb}$=.95.

Split-half reliability for *Authenticity* was assessed by randomly assigning the two items with the highest *(m11, m19)* and the one with the lowest index *(m4)* to the *first half. M5, m6, and m7* became assigned to the *second half* . The correlation was r=.77, p<.01, and reliability $r_{sb}$ =.87. In summary, the MNQ and the two sub-scales show high reliability.

## Validity

The reduced 16-item MNQ showed a negative correlation with depression (-.51, p<.01) , and a smaller negative correlation with anxiety (-.21, p<.01). The correlations of Liveliness with depression (-.52, p<.01) and anxiety (-.22, p<.01) were slightly higher than those of the Authenticity sub-scale with depression (-.45, p<.01) and with anxiety (-.17, p<.01).

Significant (p<.01) correlations with the total score of the MNQ (coefficients ranging from -.22 to -.49), with AU (-.21 to -.53) and with LN (-.21 to -.51) were found for 16 of the 18 schemas. Two schemas Unrelenting Standards/Hypercriticalness (US) and Self-Sacrifice (SS) formed a notable exception and did not correlate significantly with the Meta Needs (correlations with AU, LN and the total MNQ all between -.06 and +.1, (p>.05). To further explore this issue, the correlation which US and SS had with depression and anxiety was compared against the correlations that other schemas had. As Table 4 shows, their correlations were also in this respect among the weakest. Only one schema Emotional Inhibition (EI) had a smaller correlation coefficient with anxiety (r=.06, p>.05), and Entitlement/Grandiosity (ET) was the only schema which correlated with depression (r=.15, p>.01) less than US and SS.

**Table 4** Correlations of the Meta Needs total score and Authenticity and Liveliness sub-scales with depression, anxiety and schemas

| | MNQ_AU | MNQ_LN | MNQ_total | BDI_total | BAI_total | M | *SD* |
|---|---|---|---|---|---|---|---|
| MNQ_AU | 1,00 | | | | | 15,99 | 6,68 |
| MNQ_LN | .79 | 1,00 | | | | 23,42 | 11,21 |
| MNQ_total | .91 | .97 | 1,00 | | | 39,41 | 17,00 |
| BDI_total | -.45 | -.51 | -.51 | 1,00 | | 18,20 | 9,83 |
| BAI_total | -.17 | -.22 | -.21 | .55 | 1,00 | 18,38 | 12,31 |
| ED | -.35 | -.39 | -.40 | .32 | .16 | 5,96 | 5,58 |
| AB | -.34 | -.27 | -.31 | .39 | .31 | 9,94 | 5,24 |
| MA | -.22 | -.27 | -.26 | .30 | .29 | 10,09 | 5,67 |
| SI | -.51 | -.50 | -.53 | .48 | .23 | 10,25 | 5,90 |
| DS | -.53 | -.42 | -.49 | .46 | .19 | 6,03 | 5,44 |
| FA | -.35 | -.25 | -.30 | .46 | .17 | 5,95 | 5,51 |
| DI | -.45 | -.36 | -.42 | .47 | .24 | 5,20 | 5,09 |
| VH | -.26 | -.35 | -.33 | .32 | .39 | 9,20 | 5,48 |
| EM | -.23 | -.28 | -.27 | .28 | .27 | 7,92 | 5,39 |
| SB | -.35 | -.32 | -.35 | .41 | .24 | 8,49 | 5,35 |
| SS | .10 | -.01 | .03 | .17 | .12 | 11,97 | 5,56 |
| EI | -.31 | -.27 | -.30 | .24 | .06 | 7,20 | 5,44 |
| US | .02 | -.06 | -.03 | .16 | .13 | 13,64 | 5,24 |
| ET | -.21 | -.21 | -.22 | .15 | .16 | 13,05 | 4,74 |
| IS | -.43 | -.35 | -.40 | .30 | .15 | 11,44 | 5,01 |
| AS | -.30 | -.29 | -.31 | .26 | .18 | 14,12 | 5,32 |
| NP | -.25 | -.34 | -.32 | .36 | .34 | 11,50 | 5,58 |
| PU | -.23 | -.20 | -.22 | .29 | .15 | 10,12 | 4,5 |

*Note:* To enhance readability, correlations between schemas have been omitted, since they were not relevant for the analysis. Correlations between schema- and Meta Needs measures were found to be highly significant (p<.01) except for those with Unrelenting Standards (US) and Self-Sacrifice (SS) ( p>.05).
*Abbreviations: MNQ_total*=total score of Turkish Meta Need Questionnaire (MNQ); *MNQ_AU*=Authenticity sub-scale of MNQ; *MNQ_LN*=Liveliness sub-scale of MNQ; *BDI_total*=Turkish Beck Depression Inventory-II total score; *BAI_total*=Turkish Beck Anxiety Inventory total score.
*Schemas from the Turkish Young Schema Questionnaire - Short form-3 (YSQ-S3): ED*=Emotional Deprivation, *AB*=Abandonment/Instability, *MA*=Mistrust/Abuse, *SI*=Social Isolation/Alienation, *DS*=Defectiveness/Shame, *FA*=Failure, *DI*=Dependence/Incompetence, *VH*=Vulnerability to Harm or Illness, *EM*=Enmeshment/Undeveloped Self, *SB*=Subjugation, *SS*=Self-Sacrifice, *EI*=Emotional Inhibition, *US*=Unrelenting Standards/Hypercriticalness, *ET*=Entitlement/Grandiosity, *IS*=Insufficient Self-Control/Self-Discipline, *AS*=Approval-Seeking/Recognition-Seeking, *NP*=Negativity/Pessimism, *PU*=Punitiveness.

## DISCUSSION AND CONCLUSION

In line with humanistic psychotherapists like Maslow (1971) and Existential Psychotherapy (Prochaska & Norcross, 2010), it was proposed that there exist human Meta Needs that encompass broad concepts of life fulfillment, and are different from the core emotional needs as known in Schema Therapy. To investigate this new concept, a Meta Needs Questionnaire (MNQ) was developed. The items were derived from patient's responses to a series of questions about the positive function of their symptoms, which appeared to also serve as a maladaptive attempt to meet their Meta Needs.

Meta Needs may help to better systematize, classify and understand the nature of existentialist themes that have long been described by existentialist philosophers (Stanford Encyclopedia of Philosophy, 2010). Examples of such themes are to find meaning in life, feelings of completeness, harmony with oneself and the world, finding joy and fulfillment in one's life, instead of living a life that feels alien to oneself, and to not fully express oneself as a person (similar to the items of the MNQ, compare with figure 1). Meta Needs may be a promising approach to explain these experiences in terms of fulfilled and unfulfilled Meta Needs. If the relationship between Meta Needs, schemas, core emotional needs, and clinical symptoms can be clarified, therapists and other mental health professionals may benefit from an enhanced model. Formerly ill-defined problems like unattained self-fulfillment, spiritual suffering and crises could potentially be better understood and broken down into their 'components' (unfulfilled Meta Needs, core emotional needs, schemas, coping styles, etc.).

Using exploratory factor analysis, two underlying factors of the MNQ were identified confirming the hypothesis that fewer variables underlie the variety of items. As expected, some of the items had to be excluded because of their highly similar content, or ambiguous factor loadings. If an oblique rotation method had been chosen, the factor loadings would have been more clear-cut, but with the orthogonal rotation it was easier to identify the most unambiguous items and exclude the others, thereby reducing bias that was potentially introduced by the observational nature of the clinical procedure through which the items had been obtained. In accordance with their item content, the first factor was labeled "Liveliness" (LN), and the second "Authenticity" (AU). Although the factor analysis provided mixed evidence with regard to the choice of a one-factor or two-factor model, inspection of the item contents suggested that they could be better categorized with a two-factor model. The resulting item distribution across the two factors was found to be rather straightforward. The factors were clearly definable and their item contents allowed for an intuitive understanding of their meaning. It should be mentioned however, that this evaluation is not based on objective criteria and should therefore be evaluated with caution.

Item-analysis showed high reliability measures of the MNQ, also with regard to split-half reliability, indicating that the MNQ is a reliable tool to assess Meta Needs. The whole scale showed a moderate, negative correlation with depression, and a weak negative correlation with anxiety. This demonstrated construct validity, confirming the hypothesis, originally proposed by Maslow (1971, p.305), that frustration of Meta Needs was linked to pathologies. The Liveliness sub-scale had stronger correlation coefficients than Authenticity. A possible interpretation is that experiencing the joy of life is more contradictory to depression and anxiety, than the items that the Authenticity sub-scale consists of. Authenticity may correlate with other symptoms stronger. Furthermore, both sub-scales correlated more with depression than with anxiety, which may be due to similar reasons.

It is not possible to infer any causal relationships from the correlation analyses, but nevertheless some speculation may support the development of ideas for future hypotheses. One could speculate because of the negative correlation between Meta Needs, depression and anxiety, that Meta Need fulfillment leads to less depression and anxiety, perhaps because the increased contentment with one's life leads to less negative automatic thoughts, and better interpersonal relationships. Alternatively, reducing anxiety and depression could lead to more Meta Need fulfillment, if one assumes that this would be easier to obtain in the absence of these negative symptoms. However, the correlation is weak with anxiety, and only moderate with depression, so a situation is also conceivable where the symptoms are cured, but Meta Needs remain unfulfilled, for example after a Cognitive Behavioral Therapy or Schema Therapy intervention. It could be a consequence that the symptoms are more likely to return. If this is the case, it could be beneficial to assess and treat Meta Needs for relapse and symptom prevention.

It was hypothesized that Meta Needs would negatively correlate with the schemas, which they did, thereby demonstrating criterion-related validity of the MNQ. Unrelenting standards/Hypercriticalness (US) and Self-Sacrifice (SS) were the only exceptions i.e. they did not correlate with the schemas. According to Rafaeli et al. (2011) US is characterized by an urge to attain extraordinary high standards, often accompanied by pervasive perfectionism, rigid rules in many life circumstances, and worry about time and performance. SS is described as a strong motivation to meet the needs of other people. This is being perceived as far more important than meeting the own needs, which would lead to feelings of selfishness. Since the correlation with Meta Needs is close to 0, the question comes up why people with strong US and SS schemas apparently attain Meta Needs fulfillment as well as people who do not have these schemas. One interpretation would be that Meta Needs can be fulfilled independent from whether people strive excessively for perfection or are preoccupied with the fulfillment of other people's needs. Furthermore it is striking that US and SS correlations with anxiety and depression were almost the weakest among the other schemas. This could mean that US and SS are not indicative for both Meta Need fulfillment and psychological disorders.

The present study was conducted with Turkish participants, and cannot be generalized to populations from other countries. Furthermore the amount of participants who completed the MNQ (N=319) may not permit strong conclusions, and was further limited because not all participants completed the other questionnaires (see Table1). Gender distribution was not equal (men=95, women=224). Furthermore the study did not control for age effects, and only included patients with relationship problems or with a diagnosis of an anxiety disorder or depression. No other populations of patients and no healthy controls were tested. The design of this study was cross-sectional, which does not permit conclusion about changes in Meta Needs, symptoms, and schemas over time. The correlational nature of the research does not allow inferring causal relationships, and no test-retest reliability was measured. It is not clear to what extend the questionnaire encompasses all relevant Meta Needs, i.e. content validity was not assessed.

It is possible that regression analysis would shed more light on the relationships between clinical symptoms, Meta Needs and schemas. Future research should further test validity and reliability with different samples and use confirmatory factor analysis to verify the two-factor structure of the MNQ. If the questionnaire continues to show good reliability and validity, its relationship with clinical symptoms, schemas, coping styles, and schema domains should be explored by means of structural equation modeling. In addition, the same approach could demonstrate if these relationships explain more variance in clinical symptoms than the Schema Therapy concept without the Meta Needs. Moreover, the clinical validity of the MNQ in predicting change in symptoms during treatment should be determined in future studies. As a conclusion Meta Needs seem to be a promising concept for systematizing broad schemes of life fulfillment that are known from existentialist philosophers and humanistic psychotherapists like Maslow. Correlations with schemas and clinical symptoms of depression and anxiety were found, and the new Meta Needs Questionnaire was shown to be a valid and reliable tool for assessing Meta Needs.

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SÜMEYRA SÜRMELI

# The effect of violent games on aggression

## REVIEW

The aim of this study was to examine the effects of violent video games on aggressive behaviour when played by children and adolescents. This was done by investigating several theories and by conducting a structured literature review in which the studies were considered separate by methodology. Eight articles were included in the review after computerized searches of the psychological database PsycINFO. The results showed a small effect of violent video games on aggressive behaviour. However, several other factors have been found to play a role and to make the effect larger. Examples of these factors are wishful identification, competitiveness, arousal, and trait aggression. Gender has also been found to play an important role: the effects of the games are higher within boys when compared to girls.

**Keywords:** video games, aggressive behaviour, children, adolescents

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## INTRODUCTION

### Problem

In the past decade, there has been a significant increase in the number of children and adolescents that play video or computer games. Data from the first nationally representative study of video game play in the United States indicate that 97% of adolescents aged 12 to 17 play computer, web, portable, or console video games (in this study "video games" will be used to refer to all), with 31% of the sample playing on a daily basis and another 21% playing 3 to 5 days a week (Lenhart et al., 2008). Interestingly, half of the adolescents that were surveyed reported playing violent video games and that half of the 10 most frequently played games were violent games.

The high prevalence of violent video games raises questions about the possible psychological and behavioural effects, especially whether the violent content would lead to an increase of aggressive behaviour in children and adolescents. Aggression includes a range of behaviours which can be verbal, physical, emotional or mental. These behaviours can have consequences such as being psychologically and/or physically harmful to oneself or others and are therefore important social issues.

Many studies have been conducted in the past few years to examine aforementioned questions and to find a causal association between violent games and aggression. The results of these studies are inconsistent. There are several studies suggesting that playing games with violent contents leads to an increase of aggressive behaviour. However, there are also studies suggesting that violent games do not lead to an increase of aggressive behaviour but rather decrease aggression, and studies that found no effect of video games on aggression at all.

The aim of the present review is to examine the association between violent video games and aggression by examining, analyzing and summarizing several studies in the literature. Given the distinction between correlational and causal evidence, there are controversial results when this is done by the use of the specific question "What is the effect of violent games on aggression in children and adolescents?". Many studies are correlational and can be confounded, and only experiments can answer the question. These differences in methodology (correlational vs. causal) can explain the different results of the studies and the controversy. In this review, the results of these studies will be compared with the following research question "If you consider studies separately by methodology (i.e. correlational versus experimental), do the results in each category then become more equivocal?". The results will provide a clearer picture of the association between violent video games and aggression. The next section will first consider several theories that are relevant to the problem and relevant to address the research question correctly.

## Theoretical framework

### *Social learning theory*

According to the social learning theory of aggression, learning can result from direct experience but can also occur by observation. This latter kind of learning enables organisms to acquire large, integrated patterns of behaviour without having to form them gradually by tedious trial and error (Bandura, 1978).

According to the theory, violent video games provide both children and adolescents the opportunity to learn aggressive behaviour by observing the aggressive styles of behaviour used in the games. They will be able to imitate the aggressive character(s) of the game in real-life if they have the subskills that are necessary for the action. This ability to imitate will be more likely when the child can identify himself or herself with the game. Rewards and punishments also play a role in this theory. When children see someone rewarded after an aggressive behaviour, they are more likely to imitate the behaviour. However, this is in general only done when a real-life equivalent of the reward used in the game exists.

The social learning theory also has some predictions about specific effects of exposure to violence in the media, which we can adapt to exposure to violence on computer or video games: (1) it teaches the players aggressive styles of behaviour, (2) it changes the restraints over aggressive behaviour, (3) the players become desensitized and habituated to violence, and (4) their image of the reality becomes shaped because they cannot differentiate the game and the reality.

### *Cognitive neoassociation theory*

The cognitive neoassociation theory includes another kind of learning. Berkowitz (as cited in Anderson & Bushman, 2002) has proposed that aversive events such as frustrations and provocations, produce negative affect, and subsequently aggression. Negative affect becomes linked , through learning and conditioning during other life experiences, to various thoughts, memories, expressive motor reactions, and physiological responses (Gentile, 2003). This linkage means that when negative affect is present, it automatically activates the other responses. These responses are associated with both fight and flight tendencies, which are immediate and simultaneous. The associations of fight lead to primitive feelings of anger, whereas the associations of flight lead to primitive feelings of fear. If the fight tendency is stronger, it will most likely give rise to aggression. If the flight tendency is stronger, it will inhibit the aggression.

This so-called cognitive neoassociation theory further assumes that cues present during an initial aversive event become associated with the cognitive, emotional and motor responses triggered by the event. When these cues are present later in different situations and events, they may trigger the same responses as those present at the initial event.

Adapting these predictions of the cognitive neoassociation theory to violent video games gives rise to the suggestion that violent video games will activate related cognitive structures because the violent content will give them feelings of frustration and provocation, making it more likely that other incoming information would be processed in an “aggression” framework, possibly increasing aggressive behaviour (Griffiths, 1999).

However, higher-order cognitive processes are also taken into account in the theory. Appraisal and attribution are examples of such processes and people may use these processes to analyze their situations (by thinking about their feelings, making causal attributions and considering the consequences of acting) if they are motivated to do so. More clearly differentiated kinds feelings of anger and/or fear are produced by this deliberate manner of thought. These thoughts can also suppress or enhance the tendencies to act which are linked with the feelings. When we apply this to games, it is possible that people become less aggressive if they think about the difference between games and real-life and consider that acting in an aggressive manner like in the games will lead to serious consequences in real-life.

### *Excitation transfer theory*

Excitation transfer theory is based on the fact that the dissipation of physiological arousal occurs slowly. If two arousing events are separated by a short period of time, some of the arousal caused by the first event may transfer to the second event and add to the arousal caused by the second event (Gentile, 2003). When this is the case, an improper attribution of the arousal from the first event to the second event may occur. Thus, if the second event is related to anger, then the person should be even angrier with the additional arousal. The theory suggests that even after the arousal has dissipated, the person may still remain ready to get angry and behave aggressively when he/she attributes the heightened arousal to anger and for as long as that label persists.

This theory is relevant to the understanding of game violence because the violent content can be arousing. The arousal from the game can transfer to other emotional experiences because it dissipates slowly. If a person is already feeling angry or aroused, a violent video game can increase the intensity of this feeling because of aggressive content and thereby increase the possibility to respond aggressively. Thus, according to the excitation transfer theory, it would be expected that violent video games only increase aggression in the presence of anger from some other source or cause.

### *General aggression model (GAM)*

The general aggression model is a theoretical framework that integrates the existing domain specific or mini theories into a unified whole. The three main foci concern (a) person and situation inputs; (b) cognitive, affective, and arousal routes through which these input variables have their impact; and (c) outcomes of the underlying appraisal and decision processes (Anderson & Bushman, 2002) (Figure 1). This manner of approach in a unified whole provides a more comprehensive understanding of human aggression.

The input consists of factors that influence aggressive behaviour. These factors can be put in the category of features of the situation or in the category of features of the person in the situation. The features of the person include all the characteristics of a person that he or she brings to the situation and together form the preparedness of a person to be aggressive. Traits are relevant person factors in the theory because certain traits make persons more likely to exhibit high levels of aggression. Sex, beliefs, attitudes, and values are other examples of inputs in the category of person factors. Situational factors include all of the important features in the situation. Both types of factors have an impact on aggression by influencing cognition, affect, and arousal. Relevant factors in the category of situational features are aggressive cues, provocation, and frustration.

Input variables influence the final outcome behaviour through the present internal state that they create (Anderson & Bushman, 2002). The most relevant internal states, which are called ‘routes’ in the model, are cognition (for example ‘hostile thoughts’ and ‘scripts’), affect (for example ‘mood and emotion’ and ‘expressive motor responses’), and arousal.

The third focus of the model, which is on outcomes, consists of several complex information processes. Results from the inputs enter into the appraisal and decision processes through their effects on cognition, affect, and arousal (Anderson & Bushman, 2002) (Figure 2). These processes range from relatively automatic, called ‘immediate appraisal’, to heavily controlled, called ‘reappraisal’. The final action is determined by the outcomes of these decision processes. The final outcomes then go through the cycle to become the inputs for the next episode. The figures below illustrate the model and the way in which aggression due to violent games can be interpreted with this model.

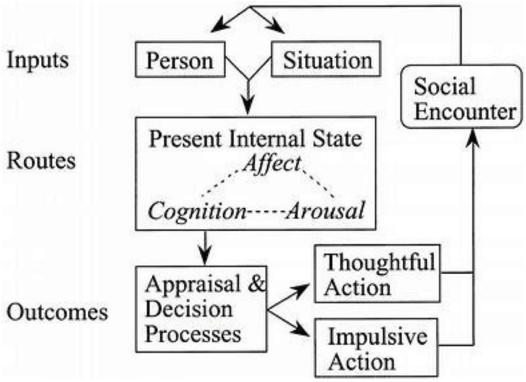

**Figure 1.** A simplified version of the main foci of the model.
Adopted from Anderson & Bushman (2002).

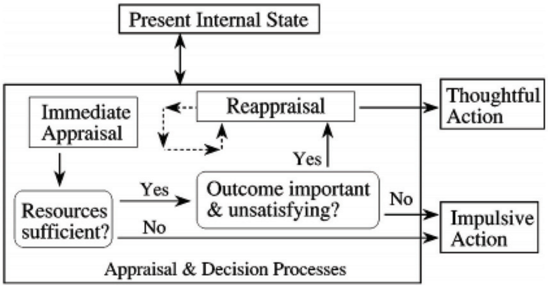

**Figure 2.** The appraisal and decision processes.
Adopted from Anderson & Bushman (2002).

## METHODS

The present study is a literature review which was conducted by finding relevant articles through computerized searches of the psychology database PsycINFO on EBSCOhost. The relevant concepts of the research question are 'aggression', 'violent games', and 'children and adolescents'. These concepts were combined together, including their synonyms, by the use of logical operators to compose the search query. The resulting search query was: (aggression OR "aggressive behaviour" OR "violent behaviour" OR "behavioural effects" OR violence) AND ("violent games" OR "violent video games" OR "violent computer games" OR "violent online games") AND (children OR adolescents). Using this search query in March 2012 on the database of PsycINFO yielded 90 hits.

These 90 articles were filtered for language and availability, leaving 48 hits that were further filtered on game violence and aggression, and original research articles, which finally resulted in 8 articles used in present review.

## RESULTS

### Correlational studies

The first study, conducted by Funk et al. (2002), investigated whether individuals with a high preference for violent games report more problem behaviours and emotions, particularly aggressive behaviour, than individuals with a low preference for violent games on a standardized self-report measure of adolescent problem behaviours. They also examined gender differences, with the prediction that the relationship would be stronger for males.

The results of the study did not support the prediction that adolescents with a preference for violent games would report more externalizing problems, such as delinquent and aggressive behaviour.

A study with a similar aim as the previous one was conducted by Willoughby et. al (2011), involving a longitudinal study investigating the link between sustained video game play and aggressive behaviour in adolescents, with the anticipation that higher levels of sustained violent video game play would be related to increases in aggression over time.

The sample of the study was 1492 students from eight high schools in Ontario, Canada. Direct aggression was assessed by the use of two scales of overt aggression. Prevalence of violent video game play was assessed by asking the participants to indicate ‘yes’ or ‘no’ to the question whether they played action or fighting video games and an index ranging from 0 to 1 was created by calculating the ratio of number of time periods (consists of grade 9, 10, 11 and 12) in which the participant reported playing those games to the number of waves that the participant completed. Both main study variables, aggression and violent video game play, were measured at each of the four time periods. In addition, each analysis included a comprehensive set of potential third variables as covariates (e.g., nonviolent video game play, overall video game play, & gender).

The first set of analyses showed that even after controlling for potentially relevant third variables, adolescents playing violent video games across years reported significant steeper increases in aggression over time when compared to participants who reported less play. However, the effect was suggested to be small. Further results showed that playing violent video games, but not playing nonviolent games, predict higher levels of aggression over time. This was still the case after controlling for stability in aggression and the third variables. In contrast, the frequency of aggression did not predict higher levels of violent video game play, which means that there was no support for the selection hypothesis. In sum, all of the three sets of analyses provide strong support for the socialization hypothesis.

A different longitudinal study about video games and aggression was conducted by Lemmens et al. (2011). The aim of the study was to expand our understanding of excessive and pathological involvement with computer or video games and how this is related to physical aggression. Specifically, the study had four aims: (1) to examine whether pathological gaming among adolescents predicted an increase in the frequency and duration of game behaviour, (2) to determine whether pathological gaming leads to an increase in physical aggression, (3) to examine whether violent content of games caused or aggravated the effect of pathological gaming on physical aggression, and (4) to examine whether there were sex differences in the possible effects of pathological gaming on aggression.

The results of the study showed that, first higher levels of pathological gaming predicted an increase in the frequency and duration of gaming six months later. This finding indicates that pathological gaming is progressive. Second, higher levels of pathological gaming predicted an increase in physical aggression six months later, regardless of a violent or non-violent content of the game. However, this effect was only found for boys and the adolescent boys in the study predominantly played violent games. This pathological involvement with violent games may have strengthened the effect on physical aggression. Finally, not just time spent playing games but time spent playing violent games, caused an increase in physical aggression.

### Experimental studies

In order to investigate the association between violent video games and aggression, Konijn et al. (2007) conducted a study and tested whether violent games are likely to increase aggression, especially when players identify themselves with the violent characters in the game. They used 99 Dutch boys from VMBO classes as participants. It was believed that male adolescents with lower educational ability may be especially vulnerable because they are more likely than others to consume violent media and are also more likely to engage in aggressive behaviour (Konijn et al., 2007).

Two weeks prior to the experiment the participants completed a questionnaire including measures of trait aggressiveness, sensation seeking, and video game exposure. Then, the participants were randomly assigned to play a violent–realistic game, a violent–fantasy game, a nonviolent–realistic game, or a nonviolent–fantasy game. After playing the game for about 20 minutes, the participants were asked to complete a competitive reaction time task with an ostensible partner. As a measure of aggression, the winner (faster response) could blast the loser (slower response) with loud noise through headphones but they were told that high noise levels could lead to permanent hearing damage. The researchers were especially interested in the first of the 25 trials because that one provides a measure of unprovoked aggression while the rest concerns aggression converged on beliefs about what the partner has done. After the task, the participants were asked to complete several rating scales. These rating scales included a measure of wishful identification with the main character in the game they had played, a measure of immersion level, and a measure of realism.

The results showed that the players of violent games were more aggressive than the players of nonviolent games. Furthermore, there was a positive relation between sensation seeking and aggression, and simple effects analyses showed a significant relation between wishful identification with the main characters in violent games and aggression, while such a relation was not found when identification with nonviolent games was the case. Another study with an ostensible partner and noise through headphones was conducted by Bartholow & Anderson (2002), using 43 undergraduate students who were not habitual game players and who first were assigned to a violent or nonviolent video game condition.

The severity of the noises that the participants set were used as a measure of aggressive behaviour and an analysis of the mean intensity settings show that participants who played the violent game, set higher levels of noise in comparison to the participants in the nonviolent condition. This finding supports the prediction that violent games could increase aggressive behaviour. Simple effects examinations revealed that the effects of playing violent games only existed for males and that females set similar levels of noise regardless of the game condition. These findings give rise to the suggestion that male adolescents may be more affected by violent video games than are female adolescents.

The study conducted by Adachi & Willoughby (2011) consisted of two pilot studies, which tested whether the games that were chosen differed or matched in terms of competitiveness, difficulty, pace of action, and violence, and two experiments.

At the first experiment, each of the 42 participants (college students) randomly played a violent game or a nonviolent game for 12 minutes. Then, The Hot Sauce Paradigm (Lieberman et al., 1999) was used for the measurement of overt aggressive behaviour. The participants had to prepare some hot sauce for another participant who does not like spicy food but in reality no other participant existed. Participants knew that the other participant had to drink whatever they prepared and could choose the intensity of hot sauce and the amount. In addition to this measurement of aggressive behaviour, a questionnaire was used to measure trait aggression and to examine the validity of The Hot Sauce Paradigm. The results of this first experiment show that there is a positive correlation between the paradigm and the trait aggression questionnaire. There was no difference in hot sauce scores between the participants who played the violent game and the participants who played the nonviolent game. This finding suggests that the violent content alone is not sufficient to produce an increase in aggressive behaviour.

As violent content alone was not found to be sufficient, the second experiment examined the effects of competitiveness. Each of the 60 participants (college students) were randomly assigned to play one of the four video games. These games included a highly competitive violent video game, a competitive nonviolent video game, a less competitive violent video game, and a less competitive nonviolent video game. The violent games were also classified into levels of a high violent content or moderate violent content. The procedure and used measurements after the game session were the same as in the first experiment: The Hot Sauce Paradigm was used to measure overt aggressive behaviour and a questionnaire was used to measure trait aggression. However, there was an additional measurement of heart rate by the use of ECG at baseline and throughout the game session. The results show that only the two highly competitive games led to an increase in the heart rate from the baseline. These two most competitive games also produced greater scores for aggressive behaviour than the less competitive games did. Another relevant finding was that the combination of a high level of violent content with a moderate level of competitiveness was not sufficient for an elevation in aggressive behaviour when compared to a game with less competitiveness and nonviolent content. These findings suggest that competitiveness plays a relevant role in the relation between video games and aggression.

The study of Fleming & Rickwood (2001) examined the effects of violent versus nonviolent video games or paper-and-pencil games on children's arousal, aggressive mood, and positive mood. In addition, gender differences and the role of prior experience with video games is examined to see whether this leads to any desensitization to violence. The participants were 36 boys and 35 girls with a mean age 10 years from a public junior school in Australia.

The independent variable of the study was the level of game violence (paper-and-pencil game, non-violent video game, or violent video game) and the dependent measures were heart rate, self-reported arousal, aggressive mood, positive affect, and general mood. Heart rate was measured by the use of a Bioview Series IV Biofeedback system and was a measure of physical arousal and the other dependent variables were measured with scales. In addition, earlier experience with video games was the covariate. Every child played all the games after being assigned to an order of game play.

The results show that playing the violent game led to a significant increase in arousal when compared to the other two game conditions. Girls were more aroused than boys. However, playing the violent game did not lead to a significant increase in aggressive mood for either boys or girls. Positive mood measured by positive affect did not show any effects but positive mood measured by general mood showed a significant increase for both genders after playing the violent video game.

The study of Unsworth et. al (2007), acknowledges the possibility of three distinct outcomes of violent video game play: a negative effect, no detrimental effects, or a positive effect on aggression. The role of predictors in the context of all three outcomes were examined.

The participants of the study consisted of 111 males and 15 females between the ages of 12 and 18 years. These participants first completed a gaming questionnaire, as a measure for game habits, and three other questionnaires that measured personality traits (psychoticism, neuroticism, and extraversion), trait anger, and trait anxiety. Then, the participants played the game Quake II, because of its violence ratings. During their playing, accessibility to aggressive thoughts were assessed by the use of the Articulated Thoughts in Simulated Situations (ATSS) Paradigm (Davison, Vogel, & Coffman, 1997). This method recorded and measured the thoughts of the participants after they were asked to talk out their thoughts loud into a microphone during the game. When the game session ended, the questionnaires on trait anger and trait anxiety were re-administered.

The results show for some people an increase, for some a decrease and for the majority no changes in anger ratings/aggression. Using state and trait variables was found to be useful to predict these reactions. A "labile" temperament coupled with high state anger at pregame-play led to a cathartic effect (decrease); a "labile" temperament coupled with low state anger at pre-game-play led to an increase in angry affect; and a "stable" temperament led to no change in angry effect following game-play (Unsworth et al., 2007). Another relevant finding of the study was that exposure to violent video game was not related to angry affect or aggression temperament.

## DISCUSSION

The first question of this study, “What is the effect of violent games on aggression in children and adolescents?” , was examined by a structured literature review. The most relevant finding in the included research articles about the effect of violent games on aggression is that there mainly was a small but no significant support for a positive effect of playing violent video games on aggressive behaviour, suggesting that a violent content alone is not sufficient to predict aggression. The second question, “If you consider studies separately by methodology (i.e. correlational versus experimental), do the results in each category then become more equivocal?”, was examined by considering the studies separately by methodology. The results show that even when studies are considered separate (i.e. correlational versus experimental), there are still inconsistent findings. The reason for this is the differences in the measurements (different scales, different games) used within the categories and the many possible confounders.

There are several results revealing that there are other factors that play a role in influencing aggressive behaviour. One of these factors is gender. Results show a greater increase in aggression for boys playing violent games, while girls were reported to have a very small increase or even no increase at all. This finding suggests that boys are more likely to be affected by violent video games. According to the results, another relevant factor is wishful identification. A significant relation between wishful identification with the main characters in violent games and aggression was found, while such a relation was not found when identification with nonviolent games was the case. The next main finding is that higher levels of competitiveness in games lead to higher levels of aggression, predicting an important role of competitiveness in the relation between violent games and aggression.

All those influencing factors actually provide support for the General Aggression Model, which is previously described and which includes all of the found factors. A support for the Social learning theory is provided by the study of Konijn et al. (2007) in which wishful identification with the characters in violent games had a positive relation with aggressive behavior (according to the theory people are more likely to imitate if they identify themselves with the model). The study of Fleming & Rickwood (2001) shows that there is an increase in general mood after playing violent games, which is inconsistent with the Cognitive neoassociation theory that suggests that violent games will lead to an increase in aggression because it will activate negative feelings and related cognitive structures.

However, more researches are needed for a better understanding of the relationship and for a clearer answer on the research question of this study.

After all these findings, it is still not possible to give a clear answer on the research question. Studies with findings that indicate an association between violent games and aggression are mostly not matched in terms of competition and pace of action for example and violent content alone is not sufficient for a significant effect, there are many other factors that have an influence on the relation between violent video games and aggressive behavior. More research has to be done to get a clearer understanding of the association and to be able to provide a clear answer on the research question.

A suggestion for future research is the examination of more factors with a possible role in the relation between violent video games and aggression at once and to match conditions in terms of game characteristics, competitiveness and pace of action. It is also relevant for future research that methods other than self-report scales are used because of the lack in reliability of these self-report scales.
Finally, we can say that there is still more research needed to be able to say something about the association between violent video games and aggression.

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