Training Components of Face Cognition: Face Memory and Speed of Face Cognition

Dissertation

zur Erlangung des akademischen Grades
Doctor rerum naturalium (Dr. rer. nat.)

im Fach Psychologie

eingereicht an der Mathematisch-Naturwissenschaftlichen Fakultät II
der Humboldt-Universität zu Berlin

von

Dipl.-Kffr. Dominika A. Dolzycka

Präsident der Humboldt-Universität zu Berlin
Prof. Dr. Jan-Hendrik Olbertz

Dekan der der Mathematisch-Naturwissenschaftlichen Fakultät II
Prof. Dr. Elmar Kulke

Gutachter

1. Prof. Dr. Werner Sommer, Humboldt-Universität zu Berlin
2. Prof. Dr. Oliver Wilhelm, Universität Ulm
3. Prof. Dr. Annekathrin Schacht, Georg-August-Universität Göttingen

Tag der Verteidigung: 08.03.2013

ACKNOWLEDGEMENTS

I wish to express my gratitude to everyone who helped and encouraged me with this work. Most of all I wish to thank Werner Sommer for providing me with this opportunity to learn and to conduct research and for his faith in me. Together with Oliver Wilhelm, they were my advisors, guided my progress over the years, and financed my research from their grant by Deutsche Forschungsgemeinschaft (DFG: Wi 2667/2-3). I am most grateful for their support. Sincere thanks to Grit Herzmann for introducing me to psychological research and for her inspiring help throughout all parts of my dissertation. I further wish to thank Winny Henkel, Birgit Stürmer, Martin Schimdt-Daffy, Carola Lehle, and Mareike Beyer for their encouragement, thought-provoking discussions, and help with comments on earlier versions of the text. I thank Andrea Hildebrandt for introducing me to and helping me with data modelling and Rainer Kniesche for assisting in programming the training regimes. I thank Romy Frömer, Guillermo Recio, Jörg Paschke, Janet Geipel, and Carolyn Nelles for assisting in data collection and Thomas Pinkpank, Eckhard Schulz, Stephan Schulz, Erik Kasswan, and Ralf Schultzik for technical support. Axel Rosenkranz I thank for disburdening me from quite a few of my chores so that I could spend more time working and Günter Abel I thank for his letter of recommendation that helped open closed doors. To my husband and children everything.

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ABSTRACT

Face cognition is a crucial skill for social interaction. Large individual differences in face cognition have been shown for healthy adults, suggesting that there might be a need for improvement, yet training of this ability has seldom been attempted. In the present studies, I developed and tested training procedures for face memory and for speed of face cognition, based on the model developed by Wilhelm et al. (2010). In Study 1, training effects were studied with healthy middle-aged participants at the behavioural level. Both training procedures enhanced performance over the course of the training. For facial speed, this improvement was significant as were the faster reaction times on all tasks for facial speed, for object speed, and for general processing speed. Thus, training of facial speed influenced a more general ability to process complex visual stimuli more quickly. Study 2 was conducted to investigate the psychophysiological underpinnings of training effects after a re-training. The facial speed training enhanced performance over the course of the re-training. In the post-test conducted directly after the re-training, the two groups did not differ in reaction times. Results within event-related components suggested that the facial speed training reduced the contributions of structural representations from long-term memory to identity recognition (N250r) and that face memory training enhanced the semantic processing of familiar faces (N400). This dissertation demonstrates the plasticity of the speed of processing complex visual stimuli. The versatility of the results and the limitations of the studies are discussed along with suggestions for future research.

ZUSAMMENFASSUNG

Gesichterkognition ist eine wichtige Fähigkeit für soziale Interaktionen. Obwohl große interindividuelle Unterschiede in der Gesichterkognition festgestellt wurden, gibt es bisher wenige Bestrebungen, diese Fertigkeit zu trainieren. In den vorliegenden Studien habe ich Trainingsverfahren für das Gesichtergedächtnis und die Geschwindigkeit der Gesichterkognition entwickelt und untersucht, welche auf dem Modell von Wilhelm et al. (2010) beruhen. In Studie 1 wurden Trainingseffekte bei gesunden Probanden mittleren Alters behavioral untersucht. Das Training des Gesichtergedächtnisses zeigte einen Trend zur Leistungsverbesserung in der trainierten Aufgabe. Das Training der Geschwindigkeit der Gesichterkognition verkürzte signifikant die Reaktionszeiten in allen Geschwindigkeitsaufgaben der Gesichterkognition, der Objektkognition sowie der mentalen Geschwindigkeit. Daher wird angenommen, dass das Geschwindigkeitstraining eine allgemeine Fähigkeit, komplexe visuelle Stimuli zu verarbeiten, beeinflusst hat. In Studie 2 wurden nach einem Re-Training die psychophysiologischen Grundlagen der trainingsbedingten Veränderungen untersucht. Das Geschwindigkeitstraining verkürzte zwar die Reaktionszeiten im Verlauf des Re-Trainings, jedoch unterschieden sich die beiden Trainingsgruppen nicht im folgenden Posttest. Die Auswertung der ereigniskorrelierten Potentiale wies auf eine Reduktion der strukturellen Repräsentationen aus dem Langzeitgedächtnis zur Erkennung von Individuen (N250r) durch das Geschwindigkeitstraining und auf eine Verstärkung der semantischen Verarbeitung von bekannten Gesichtern (N400) durch das Gedächtnistraining hin. Die vorliegende Arbeit zeigt die Plastizität der Verarbeitungsgeschwindigkeit für komplexe visuelle Stimuli auf.

TRAINING COMPONENTS OF FACE COGNITION: FACE MEMORY AND SPEED OF FACE COGNITION

I Introduction

1 Impact of Face Cognition Ability

Face cognition is essential for successful social interactions. Faces provide valuable information on aspects like familiarity, emotion, gender, or health. Many professions require face cognition skills. They are premised on the assumption that everyone has the same ability to perceive, memorise, and recognise faces. Recently, research on individual differences has indicated that though adults are all equally experienced in face cognition there are large interindividual variations in the development of this skill (T. Grueter, Grueter, & Carbon, 2008; Herzmann, Kunina, Sommer, & Wilhelm, 2010; Neta & Whalen, 2011; Rotshtein, Geng, Driver, & Dolan, 2007; Sekiguchi, 2011; Wang, Li, Fang, Tian, & Liu, 2012; Wilhelm et al., 2010). While some individuals are extremely good at recognizing faces they have seen before (Russell, Chatterjee, & Nakayama, 2012; Russell, Duchaine, & Nakayama, 2009), others range at the lower end of this distribution (see Avidan, Thomas, & Behrmann, 2009, for review). Specifically, the recognition of unfamiliar faces, as required for border control or other security relevant professions, is error prone (Hancock, Bruce, & Burton, 2000; Megreya & Burton, 2006). It would be preferable if persons performing occupations requiring good face cognition ranged in the middle or even at the higher end of the distribution of this skill. Yardley and colleagues (2008) reported that poor face cognition skill can cause problems in interpersonal relations and expand to occupational difficulties. Intervention procedures have been helpful in enhancing social functioning, like facial emotion recognition in patients with autism or with schizophrenia (e.g., Bolte et al., 2006; Hopkins et al., 2011; Wölwer et al., 2005). A training of face cognition might be needed to help those individuals who wish to improve this skill for personal and professional use. Also, experimental training studies on face cognition can contribute to the understanding of the psychological processes underlying this skill. It is the scope of this dissertation to develop and test two such training procedures.

The following sections of this chapter introduce models of face cognition on which the training procedures are based and describe the requirements training studies should meet. Next, the relevant literature on training is summarised and the two studies conducted for this dissertation are briefly introduced.

2 Models of Face Cognition

The main aim of scientific research is the consolidation of singular findings into general theories and models. Such models are the basis of further research. Therefore, this chapter describes selected models of face cognition and outlines the theoretical foundation for this dissertation. The classical cognitive model by Bruce and Young (1986) will be introduced first and followed by its extensions. Then, the three factor model of face cognition developed by Wilhelm et al. (2010), which is the starting point for the studies presented here, will be delineated.

Bruce and Young (1986) have proposed a model that can be termed classic because it has been the basis for many later models. It consists of seven cognitive processing stages. First, structural features are extracted and composed into a viewer-centred primary sketch. From here, expression, facial speech, and directed visual processing are analysed in parallel, whereas face recognition proceeds hierarchically. For face recognition, the percept extracted in the first step is compared to representations of faces stored in long-term memory, namely in face recognition units. If the percept matches a representation and the face recognition unit is sufficiently triggered, then further semantic information can be activated in units termed person identity nodes. Psychophysiological measures thought to correspond to the stages of identification and of memory related process of this model were used in Study 2. However, this model has not remained undisputed, mainly the independence of the parallel processes has been questioned (e.g., Bruyer, Mejias, & Doublet, 2007; Bulthoff & Newell, 2004; Lander & Metcalfe, 2007; Rossion, 2002; for review, see Young & Bruce, 2011).

The prototype theory extends the model by Bruce and Young (1986) on the nature of the face recognition units. Here, the face recognition unit is supposed to contain an average of all experiences with the given face (Benson & Perrett, 1993; Burton, Jenkins, Hancock, & White, 2005; Hurlbert, 2001; Nishimura, Maurer, Jeffery, Pellicano, & Rhodes, 2008; for review, see Jenkins & Burton, 2011). The quality of the average increases with the number of images entered into this computation (Bindemann & Sandford, 2011). At the same time, non-diagnostic pictorial information is eliminated by the averaging. A recent and most interesting consideration by Burton, Jenkins, and Schweinberger (2011) extends this prototype view from a single average image to a set of average images defining dimensions of a statistically probable space. The authors demonstrate such an episodically generated space of dimensions for texture and shape. Individual variations, which are statistically probable within the range of past experiences, are accepted as recognition, whereas experiences outside of this range are rejected.

A connectionist extension of the model by Bruce and Young (1986), the interactive activation model, has been suggested by Burton, Bruce, and Johnston (1990). It consists of units organised in groups with inhibitory intra-group connections. The connections between the groups are excitatory and bidirectional. The authors assumed separate face recognition units for every known face. When a familiar face is perceived, the face recognition unit and from there the domain-general person identity node are activated. Familiarity decisions are taken at the person identity level, which is explicitly assumed to be separated from the semantic information units. Brédart, Valentine, Calder, and Gassi (1995) suggested that semantic information might be stored in domain-specific separate groups.

Based on results of studies using functional magnetic resonance imaging, positron emission tomography, and event-related potentials, Haxby, Hoffman, and Gobbini (2000) introduced the neurobiological model of a distributed human neural system for face perception. The model postulates that specific brain regions underlie certain functional aspects of face recognition. A Core System is designated to visual analysis of faces and an Extended System is engaged in extracting further information from those faces. The Core System incorporates three regions of visual extrastriate areas with bidirectional interconnections via neuronal projections. First, the inferior occipital gyri analyze the early perception of basic facial features. Second, the superior temporal sulcus captures the changeable aspects of faces that bare important social information like expressions or gaze direction. Third, the lateral fusiform gyrus is important for the invariant aspects of face identification. Haxby and Gobbini (2007) modified their model to better account for recognition of familiar faces. They suggested that “theory of mind” brain areas are active and supply the system with semantic information associated with recognition of familiar faces. Further, amygdala and insula were incorporated into the distributed network for the emotional aspects of familiar face recognition.

A different approach to learn more about the ability of face cognition is to study its structure. Using a multivariate approach based on psychometric intelligence research Wilhelm et al. (2010) established a three factor model of face cognition consisting of the component abilities face perception, face memory, and speed of face cognition. Face perception is the ability to perceive facial features and their configuration exactly. It is measured with indicators based on perceptual comparisons devoid of memory load. Face memory is the ability to recognise learned faces. It is measured with tasks that involve memorising faces and their subsequent recognition. Speed of face cognition[1] encompasses the swiftness of perception, learning, and recognition of faces. Therefore, indicators of this component ability are based as well on perceptual comparisons as on recognition of faces, but the tasks are easy so that individual differences emerge as differences in response times. Face perception and face memory are highly correlated, whereas the component ability of facial speed is unrelated to them. These three component abilities constitute face specific skills that were shown to be distinct from the established ability constructs of immediate and delayed memory, mental speed, object cognition, and general cognitive ability. Hildebrandt et al. (2010) replicated the three factor model and showed that face cognition ability remains invariant over the age range from 18 to 88 years. This three factor model of face cognition is the basis for the

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[1] In the following speed of face cognition will be also termed “facial speed”.

development of the two training procedures aiming at component abilities of face cognition, namely face memory and speed of face cognition.

3 Requirements for Design and Evaluation of Training Studies

In his substantial analysis of the training research, Klauer (2001) defines training as repeated activities that aim to increase the ability needed to perform a task. Several recommendations for the design and evaluation of training studies can be deduced from the literature. The recommendations concern assessment of validity for the training, proof of persistence of training effects, choice of control group, adaptation of task difficulty, and methodology for the assessment of effects. These considerations will be outlined in the following sections.

There are different aspects of validity that should be considered when designing or evaluating a training study (Klauer, 2001). Convergent validity asks if training influenced the ability it aimed at. Construct validity assesses whether training affects the underlying ability needed to perform such a task and not only the performance on the specific trained task. Criterion validity refers to the degree to which the criterion variable is correlated with other validated measures for the skill aimed at. Discriminant validity demands that the training does not influence other abilities than the one trained. For if an intervention affected further abilities then its indication should be reassessed. These aspects should be substantiated for every training study (Klauer, 2001).

In the training literature, some aspects of validity are addressed as transfer (e.g., Hager & Hasselhorn, 2000; Klauer, 2000; Li et al., 2008; Malpass, Lavigueur, & Weldon, 1973). Near transfer can be assumed if the tasks applied for the measurement of training effects and the test context vary from the trained tasks and test context. Thus, considerations of near transfer combine requirements of criterion and construct validity. Far transfer assesses if other than the targeted abilities have been influenced and corresponds to the demand for discriminant validity.

Belmont and Butterfield (1977) demanded that for a successful training the effects should persist over time. Hager and Hasselhorn (2000) even include persistence in their definition of training. They define training as aimed to influence an ability or a skill over a period of time that exceeds the duration of the intervention itself. Persistence of training effects distinguishes training from effects related to adaptation, voluntarily induced shifts of response strategy, or other effects of short duration (Green & Bavelier, 2008). To account for persistence over time the classical pre- and post-test design should be extended by a follow-up measurement. If the gains of the experimental group are still larger than those of the control group in the follow-up measurement, then persistence may be assumed (Driscoll, Dal Monte, & Grafman, 2011; Hager & Hasselhorn, 1998).

The results of an intervention group should be compared to those of a control group in order to control potential confounding factors (Hager & Hasselhorn, 2000; McArdle, 2009). A prevalent practice among training researches is the comparison to a no-contact control group whose performance is assessed with the pre- and post-test (e.g., Chein & Morrison, 2010; Jaeggi, Buschkuehl, Jonides, & Perrig, 2008; Kesslak, Nackoul, & Sandman, 1997). Such an approach rules out simple test-retest gains, but it disregards confounding effects resulting from differences in expectancy and motivation. Studies with no-contact control groups tend to overestimate the training-induced effects (Melby-Lervåg & Hulme, in press). Klauer (1995) suggested correcting the effect sizes reported in these studies. A more elegant means to control for differences in expectancy or motivation is to contrast two training procedures and to use each practice group as the other one´s control group (Morrison & Chein, 2011; Ranganath, Flegal, & Kelly, 2011; Schmiedek, Lövdén, & Lindenberger, 2010). The control group should complete an alternative program, identical to the studied intervention in all aspects, like duration, intensity, or equipment, except for the factors that the intervention aims to influence. Such active control groups achieve similar levels of motivation and self-concept without influencing the targeted ability (Shipstead, Redick, & Engle, 2012). To help control possible confounding variables, random assignment of participants to groups is required.

A further consideration for the design of training studies is the choice of difficulty level for the training task. Computerised training procedures allow for adaptation of difficulty to individual performance. In literature on training working memory, adaptive training regimes were found to be more effective than non-adaptive ones (Holmes et al., 2010; Jaeggi, et al., 2008; Klingberg, Forssberg, & Westerberg, 2002; see Klingberg, 2010, for review). Ball, Edwards, and Ross (2007) analysed six studies investigating effects of training elderly participants on speed of processing. They found that even standardising difficulty in some sessions leads to smaller improvements than individual customisation throughout the training procedure. Thus, adaptation of task difficulty to individual performance might be an important factor for an effective training.

When evaluating the effectiveness of a training intervention, beyond testing the empirical data for statistically significant differences, effect sizes should be reported and considered (Hager, 2000b; Klauer, 2002). Effect size measures are less susceptible to the influence of sample size than p-values are (e.g., Bortz & Döring, 2006, p. 28). Thus, effect sizes are more meaningful measures for evaluation of intervention effects and are used in reviews and meta analyses of training (Kirk, 2007; Melby-Lervåg & Hulme, in press).

Another concern in numerous training studies is their lack of profundity in the assessment of training effects (compare Jaeggi, et al., 2008; Klingberg, 2010). If training effects are measured via single tasks, then post-test gains do not provide definitive evidence that an underlying ability has been influenced (Byrne, 2001; Shipstead, et al., 2012). Analysing training effects with multivariate methods allows to assess the training effects at the latent ability level with respect to the theoretical construct modelled (e.g., McArdle & Aber, 1990). Further, such methods require assessing the training-induced changes with several indicators for each latent factor, thereby providing information on correlations with other indicators for the trained ability. This is the method of choice for testing convergent, construct, and criterion validity.

Summarising the literature, a training intervention should aim to influence a skill in a persistent manner. This requires a design with at least three measurement time points: pre-test, post-test directly after the training, and a follow-up measurement. Beforehand, the construct validity should be considered with regard to theory and the training should be designed accordingly. The results should be compared to those of a control group, which received a treatment that did not influence the factors the training aimed at but otherwise was as similar to the training as possible. The effects should be measured with different tasks tapping the same ability (near transfer) and, additionally, the effects should be controlled by assessing performance on other abilities (far transfer). How these requirements were realised in this dissertation will be discussed in detail in Chapter II.

4 Review of Literature on Training Face Cognition

Studies on training face cognition date back to the 70s and 80s. These investigations aimed at contrasting the outcomes of different general training procedures, but they were not effective or even had negative effects. For example, Malpass (1981) trained different groups in feature analysis, global personality judgement, global facial judgement, or repeated face recognition tests in 12 one hour sessions. However, the training reduced face cognition within all groups. Likewise, Woodhead, Baddeley, and Simmonds (1979) found no reliable gains after three training sessions in either memorising or categorising faces. In two other studies, the recognition of faces from other ethnic groups was trained for 1.5 or 4 hours (Elliott, Wills, & Goldstein, 1973; Goldstein & Chance, 1985). Training improved recognition for faces from the trained ethnic group, but it did not increase performance for faces from the own ethnic group. Malpass, Lavigueur, and Weldon (1973) reported on two experiments. In their first experiment, they combined different durations of training (2, 4, or 8 hours) with three different verbal training strategies (describing faces, recognizing faces from descriptions, or describing differences between triads of faces) and found that none was effective on visual face recognition. In their second experiment, training lasted less than an hour and combined practice on faces of a certain ethnic group (own or not-own) with different feedback methods (no feedback, verbal feedback, electric shock feedback). For faces from the own ethnic group, they found a decrease in performance. Sporer (1991) compared encoding strategies of different depths and could show that deeper encoding strategies were superior to mere feature-based strategies but performance did not exceed that of a control group, which encoded faces without instructions. A more recent work found that general, unspecific practice did not increase the ability of face cognition (Chiller-Glaus, Schwaninger, & Hofer, 2007). Three experiments compared the performance of identity verification for novices, passport inspectors, and police officers of a specialist investigating task force for upright as well as for inverted photographs. Performance was highly error-prone, further reduced by inversion, and most interestingly did not differ between security personnel and novices. These results indicate that mere exposure or the repeated act of identifying faces does not suffice to enhance face cognition ability.

The studies cited above were not effective or even had negative effects. Three main reasons for this ineffectiveness of face cognition training are offered. First, the trainees were already at their ceiling performance of face cognition due to the extensive everyday experience they have had with faces (Elliott, et al., 1973; Goldstein & Chance, 1985; Malpass, 1981; Sporer, 1991; Woodhead, et al., 1979). Second, the costs of strategy switching at the beginning of such a strategy change might have compensated possible increases or even exceeded them (Kliegl & Philipp, 2006; Malpass, et al., 1973; Sporer, 1992). All of the above studies were aimed at the general ability of face cognition in contrast to specific aspects of this ability and were of short duration. Since participants had own strategies for recognizing and remembering faces developed in everyday life situations these short interventions might have led them to abandon their strategies and replace them with not yet sufficiently trained new ones (Goldman, Mertz, & Pellegrino, 1989; Klauer, 2001; Kliegl & Philipp, 2006; Kliegl, Philipp, Luckner, & Krampe, 2001; Maichle, 1992). In a more recent study, Kliegl and Philipp (2006) developed a training for face-name associations requiring participants to practice over a period of several months and to include this deliberate practice as well as possible into their everyday lives. Through this very extensive training two of three older adults (aged over 70) succeeded in improving their memory for face-name associations. However, this study was not well controlled and, thus, is hardly replicable. Third as Malpass (1981, p. 285) constitutes, insufficient understanding of the processes underlying face cognition might have hindered the development of effective intervention programmes and thus resulted in not finding the intended effects.

The effectiveness of training procedures as well as the processes underlying face cognition have been further investigated since the 80s. Recent training literature recommends concentrating on specific abilities (Schmiedek, et al., 2010; Smith et al., 2009). The following paragraph reviews literature on narrowly focused training procedures for persons with deficits. A summary of research on plasticity of perception follows. Next, recent studies specifically aimed at training the component ability of face perception are reported. The last paragraph summarises this section.

Newer training studies are more specific and often aim at particular deficits. Numerous studies showed that patients with Alzheimer’s dementia succeeded in learning of face-name pairs through everyday practice (Kesslak, Nackoul, & Sandman, 1997; Moore, et al., 2001; Sandman, 1993), as did patients with cognitive deficits (Belleville et al., 2006). Patients with schizophrenia improved their facial affect recognition after training aimed specifically at this deficit (Frommann, Streit, & Wölwer, 2003; Wölwer, et al., 2005). Persons with Asperger syndrome or high-functioning autism practised recognition of complex emotions and significantly improved on measures of close generalisation (Bolte, et al., 2006; Golan & Baron-Cohen, 2006). Faja and colleagues

(2012) trained persons with high functioning autism spectrum disorders in recognition of faces or houses. Their results were stimuli specific, thus, only training with faces improved face recognition and led to changes in electrophysiological measures of face perception. Visual discrimination training with face-like objects named 'Greebles' revealed that extended practice rendered expert-like performance (Gauthier & Tarr, 1997: 7-10 h; Gauthier, Tarr, Anderson, Skudlarski, & Gore, 1999: 7 h; Rossion, Kung, & Tarr, 2004: mean 9 sessions; for a review, see Bukach, Gauthier, & Tarr, 2006). Similar expertise levels for Greebles were achieved in case studies with individuals with prosopagnosia (Behrmann, Marotta, Gauthier, Tarr, & McKeeff, 2005: 31 sessions; Duchaine, Dingle, Butterworth, & Nakayama, 2004: 5 h), or with other objects classes (Wong, Palmeri, & Gauthier, 2009). Taken together, results of these studies demonstrate that persons with selective deficits benefit from extensive and specific training.

One prerequisite of recognition is perception. Numerous studies demonstrate that perception can be increased by training (for reviews see: Fahle, 2005; Kelly, Foxe, & Garavan, 2006). Training has been shown to improve the detection of signals that are overlaid by noise (Chung, Levi, & Li, 2006; Dosher & Lu, 2006). Further support for the plasticity of perception comes from studies with practice on visual discrimination tasks, for example contour perception (Rubin, Nakayama, & Shapley, 1997) or shape discrimination (Sigman & Gilbert, 2000; Yi, Olson, & Chun, 2006).

There are a few recent studies that specifically investigated training of face perception, one of the component abilities of face cognition. Training identification of either upright or inverted faces strongly increased performance on the trained identities and the trained view (Hussain, Sekuler, & Bennett, 2009). These results generalised only slightly to new faces and to the untrained orientation hinting at specificity of perceptual learning. Though, general training of face cognition did not improve performance for persons with prosopagnosia (Behrmann, et al., 2005; Duchaine, et al., 2004; Ellis & Young, 1988), several case studies reported positive effects of specific face perception training (Brunsdon, Coltheart, Nickels, & Joy, 2006; Caldara et al., 2005; DeGutis, Bentin, Robertson, & D'Esposito, 2007). For example, over three months of training on discriminating faces by their spatial configuration improved face identification to the level of healthy controls (DeGutis, et al., 2007). Performance for holistic processing of untrained other race faces improved in contrast to performance for the trained own race faces in a study applying a shorter version of the same training procedure (DeGutis, DeNicola, Zink, McGlinchey, & Milberg, 2011). The plasticity of face perception was investigated in persons without face cognition deficits in two studies (Chiller-Glaus, 2009). In one study, the effects of participation in a portrait painting course were analysed and, in the other, the effects of training perceiving differences between morphs of faces. Deliberate practice influenced performance in both studies as intended, but the effects were small.

To summarise, the studies reviewed above indicate that specific training procedures with participants with deficits, expertise training with face-like objects, as well as specific training of face perception improved performance as intended. Besides face perception training, further specific training procedures for face cognition can be derived from the three factor model by Wilhelm et al. (2010), namely training of face memory and of speed of face cognition. The next chapter explicates on the scope of this dissertation to train two component abilities of face cognition.

5 Training Component Abilities of Face Cognition

As elaborated on at the beginning of this chapter, there are substantial individual differences in the ability of face cognition. Surprisingly, training this socially important ability in healthy adults has been largely neglected in recent research. Only few of all of the above-mentioned studies investigated training of face perception. Chiller-Glaus (2009) conducted the sole study with healthy trainees and showed that specific training of face perception may improve performance. None of the studies above was designed to directly address the question of training the other two component abilities face cognition. Therefore, this dissertation investigated training effects in face memory and speed of face cognition in healthy middle aged population. This approach is based on the premise that training cognitive component abilities can enhance the ability itself (Klingberg, 2010; Shiran & Breznitz, 2011). Also, an effective training might be interesting for people engaged in occupations which require good face cognition ability. A large scale internet-based study of face memory, with over 60.000 participants, found that performance on this ability peaks in the early thirties (Germine, Duchaine, & Nakayama, 2011). Hildebrandt et al. (2010) showed that age-related decreases in the component ability of speed of face processing begin in the thirties and face memory in the forties, whereas the component ability of face perception stays preserved until the sixties. Thus, development of an effective training for the two component abilities that start to decay earlier might bring a remedy for persons still engaged in professional life. This work is the first attempt to specifically train face memory and speed of face cognition. Next, the general design and the two studies conducted for this dissertation will be delineated briefly.

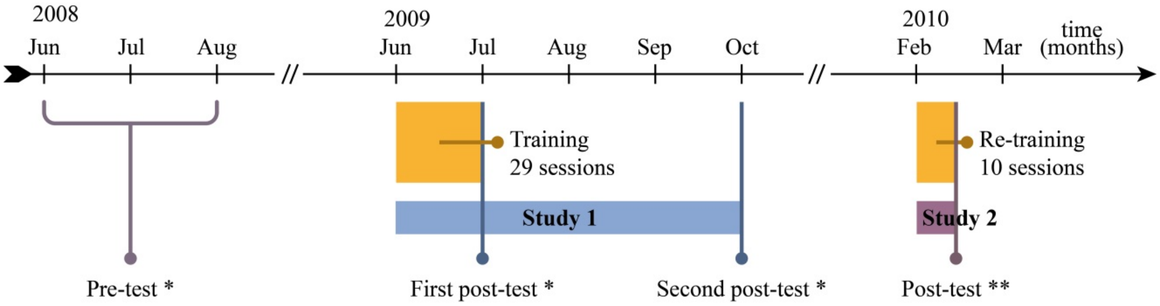

Figure 1. Schematic illustration of the timeline of the training studies, behavioural testing (*), and the testing with recording of event-related potentials (**).

Figure 1 offers a schematic presentation of the timeline of the studies and the testing. Data collected by Hildebrandt et al. (2010) served as pre-test. Study 1 was conducted to investigate the effects of training component abilities of face memory and facial speed on the ability of face cognition. Two computerised training procedures were developed. Participants, who were recruited from the pre-test study, trained on adaptive tasks for approximately 15 minutes per day for 29 days at home. The effects were assessed with a wide range of tasks. Besides tasks measuring performance on face and object cognition, further indicators for far transfer were included, i.e. for immediate and delayed memory, general cognitive ability, and mental speed. Multivariate modelling methods were employed to investigate the influence of the two training procedures at the latent ability level.

In Study 2, the influence of those two training procedures was further investigated at the psychophysiological level. A re-training, consisting of 10 sessions, was administered to the same participants. It was intended to localise changes induced by the two training procedures by analysing event-related potentials (ERPs). ERPs are often used to investigate the temporal dynamics of neural activity (e.g., Paller et al., 2003). There are ERPs that are regarded as indicators of reaction time shortening (e.g., Masaki, Wild-Wall, Sangals, & Sommer, 2004), as well as indicators that are assumed to reflect specific face processing stages of the models described above (for review, see Schweinberger, 2011).

By comparing the effects of the two training procedures at the behavioural and the psychophysiological level, the results of studies presented here should contribute to a more detailed understanding of skill development and plasticity of face cognition ability.

II Study 1

1 *Introduction Study 1*

As elaborated on in Chapter I, there might be a need for training face cognition. The main aim of this study was to develop and to test specific training procedures for two component abilities of face cognition: face memory and speed of face cognition. This study was designed as a pre-post-test experiment with a second post-test for two parallel training interventions. Data collected by Hildebrandt et al. (2010) served as pre-test and provided detailed information for matching participants. Two post-tests examined training effects. The first post-test was administered directly after the training intervention and the second three months later. Each of the two training procedures was intended as an intervention and as an active control condition for the other training procedure. The aims of Study 1 can be specified as follows:

1. Effectiveness was to be tested at different levels.
2. Specificity of the effects was to be established.
3. The model of face cognition established by Wilhelm et al. (2010) and confirmed by Hildebrandt et al. (2010) was to be replicated measured on a subsample recruited from the latter study, thus, investigating whether the component abilities are stable over time.

2 *Method of Study 1*

2.1 *Participants*

Participants were recruited from the study conducted by Hildebrandt et al. (2010). The authors tested face cognition with a wide range of tasks. They further included indicators of object cognition and other cognitive abilities that might contribute to face cognition. Hence, it was possible to match the groups for this training study on a multitude of parameters. Sixty middle-aged subjects, who consented to participate in the training study, were assigned to one of three matched groups. Further 59 participants were recruited from the same study. The latter group, termed here as unmatched control group, was needed to obtain a sample size adequate for calculating structural equation models and participated in the pre- and first post-test.

For matching, triads of persons with similar factor scores on the component abilities of face cognition were created. The three persons of each triad were then randomly assigned either to one of the two training groups or to the matched control group (for details see Table 1). The three matched groups did not differ in initial factor scores on face memory, face perception, speed of face processing, general cognition, immediate and delayed memory, and mental speed, nor in age or gender.

Table 1. Sample Means and Standard Deviations for Practice and Control Groups

	Practice groups		Control groups		*p**	*f**
	Memory	Speed	Matched	Unmatched		
FS face perception	.39 (.73)	.29 (.73)	.40 (.64)	.18 (.88)	.62	.14
FS face memory	.44 (.67)	.31 (.77)	.36 (.81)	.20 (.89)	.69	.10
FS face speed	.24 (.65)	.25 (.61)	.21 (.87)	.12 (.92)	.91	.10
Age	44.8 (8.3)	42.7 (8.8)	43.1 (11.4)	46.1(18.2)	.76	.10
FS general cognition	.10 (.17)	.05 (.17)	.04 (.25)	.03 (.23)	.65	.18
FS immediate and delayed memory	.63 (.08)	.66 (.10)	.62 (.10)	.66 (.08)	.26	.03
FS mental speed	1.05 (.11)	1.07 (.13)	1.07 (.10)	1.05 (.11)	.79	.10

Note. FS: factor score; SDs are in parenthesis.
** p-value and effect size f for the comparison of three matched groups (memory, speed, and matched control).*

Initially, each matched group comprised 20 participants. During the training period, one participant dropped out of the memory group. Thus, 19 adults (10 women) aged between 28 and 58 years completed the face memory training. Further 20 adults (10 women) aged between 27 and 57 years completed the facial speed training. Twenty adults (7 women) aged between 27 and 60 years formed the matched control group and 59 adults (35 women) aged between 17 and 70 years the unmatched control group. Trainees were paid 88 EUR plus an additional 6 to 24 EUR based on their performance. Participants of the unmatched control group received 21 EUR and of the matched 45 EUR.

Due to technical problems with the training tasks included in the first post-test, the data of three participants were not registered. This applied to data of one person from each training group for the trained speed task and to one person from the matched control group for the trained memory task.

2.2 General Training Procedure

There were two different training procedures: one aimed to enhance the face memory and the other to enhance the speed of face cognition. Participants completed their first training sessions in groups in the presence of an experimenter. This gave them the opportunity to become acquainted with the handling of the notebook PCs and with the training tasks. Subsequently, they practiced at home. Utilising computers took advantage of three crucial points discussed by Tam and Man (2004): First, the intervention procedures were standardised. Second, routines were flexible and adaptive. They set the difficulty according to the on-line recorded achievement at challenging, but not frustrating, levels. Third, the programmes were designed to be self-paced and to provide immediate consistent non-judgemental feedback.

Reward points were given to motivate participants to improve their performance. Participants were encouraged to accumulate as many points as possible and informed that, at the end of the training, the points would be recalculated into a monetary reward. Trainees were instructed to keep the time of day, place, and light situation as constant as possible. Compliance was monitored via weekly mailings of electronic data from each session. Participants in both groups trained daily for approximately 15 minutes for 29 days. In both training procedures, the order of trials was the same for all participants.

2.3 Training Face Memory

2.3.1 Stimuli

All stimuli were artificially generated faces (FaceGen Modeller 3.2) of neutral facial expression aged 20 to 40 years. Female and male faces were equally represented. None of the faces contained external features (hair, beards, earrings, or glasses). For each session 9 target faces were generated. For each target, four further faces were produced in order to morph them into distracters. Face models were imported into Cinema 4D 11.0. Because the originally created models were bald, hats were added in order to make their appearance more natural. Next, each target model was morphed with 9 different amounts of the distracter faces. Only male–male and female–female morphs were created. Each morph was rendered with different camera settings resulting in three views: one frontal view and two profile views of the left side at 30° and at 60°. This produced a total of 972 images for each session (9 targets x 4 faces for morphing of distracters x 9 morph combinations x 3 views).

All face images were embedded in a white background and then scaled to 400 x 400 pixels (82 x 82 mm). They were displayed on a 14-inch LCD display of a notebook (with a resolution of 1280 x 800 pixels) and freely viewed at a distance of about 50 cm, where they subtended to a visual angle of approximately 9.4° x 9.4°.

2.3.2 Training Procedure for Face Memory

The training was comprised of a study block (Figure 2, Panel A) followed by a filler task and six test blocks (Figure 2, Panel B). The filler task was a general knowledge quiz with three multiple choice questions followed by the display of the correct answers. It lasted 1.5 minutes. From the second session on, three blocks with faces learned the previous session were administered before the study block.

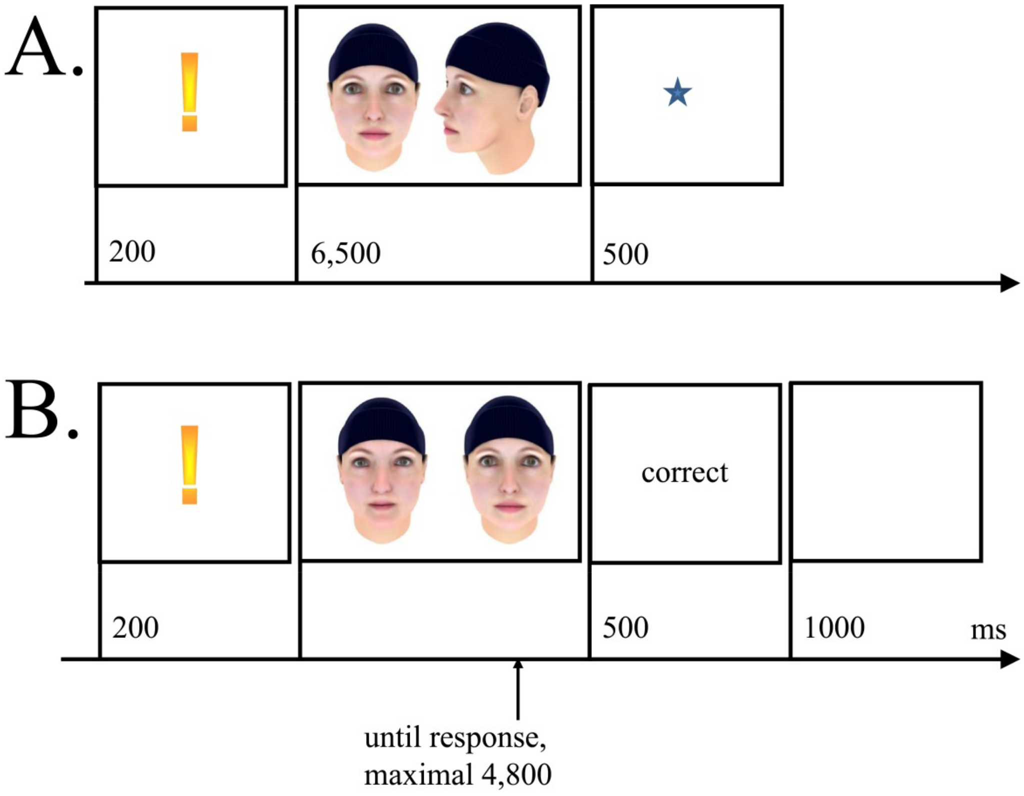

Figure 2. Trial sequences from the face memory training of a learn trial (Panel A), and of a test trial with feedback for a correct answer (Panel B).

2.3.3 Task for the Face Memory Training

Nine target faces had to be memorised every day in the study block. A learning trial started with an exclamation mark presented for 200 ms, which was replaced by two images depicting the same face in frontal view and a 60° profile for 6.5 s. A fixation star, shown for 500 ms, marked the end of the trial. The instruction encouraged to memorise both views as well as possible.

A test block comprised 18 trials presented in a two-alternative forced-choice paradigm with a familiarity task, two trials for each target face. A test trial started with the presentation of an exclamation mark for 200 ms, followed by two faces, a target and a distracter face displayed until reaction or up to 4.8 s. Trainees were asked to press the Alt- or the Alt-Gr-button on the keyboard with their left and right index finger, respectively, on the side corresponding to the presentation of the target. The two faces were always of the same gender and depicted in the same view. For each response, feedback was displayed for 500 ms. The German words for “correct” (richtig), “incorrect” (falsch), “faster, please” (schneller, bitte), and for “do not guess, please” (bitte nicht raten) appeared as feedback on the screen. The trial ended with a blank screen for 1 s (intertrial interval).

At the end of each block, feedback about performance in that block was presented. The sum of hits, reward points scored in this block, and the level of difficulty for the next block were displayed. At the end of each session, participants were shown an overview of the levels they trained on in each block, the total of reward points scored in this session, and were informed whether or not this had been the best performance so far.

In the first and third block, recognition of the frontal view, in the second and fourth block recognition of the 60° view, and in the fifth and sixth block recognition of the 30° views was tested. The view of 30°, which had not be seen during learning, was included to ensure that faces and not only images had been learned (Kaufmann, Schweinberger, & Burton, 2009).

2.3.4 Adaptation

A dynamic adaptation procedure aimed to maximise and to smooth the challenge across participants while keeping their motivation high. Different levels of difficulty were created by morphing different amounts of the target face into the distracter (compare Figure 3).

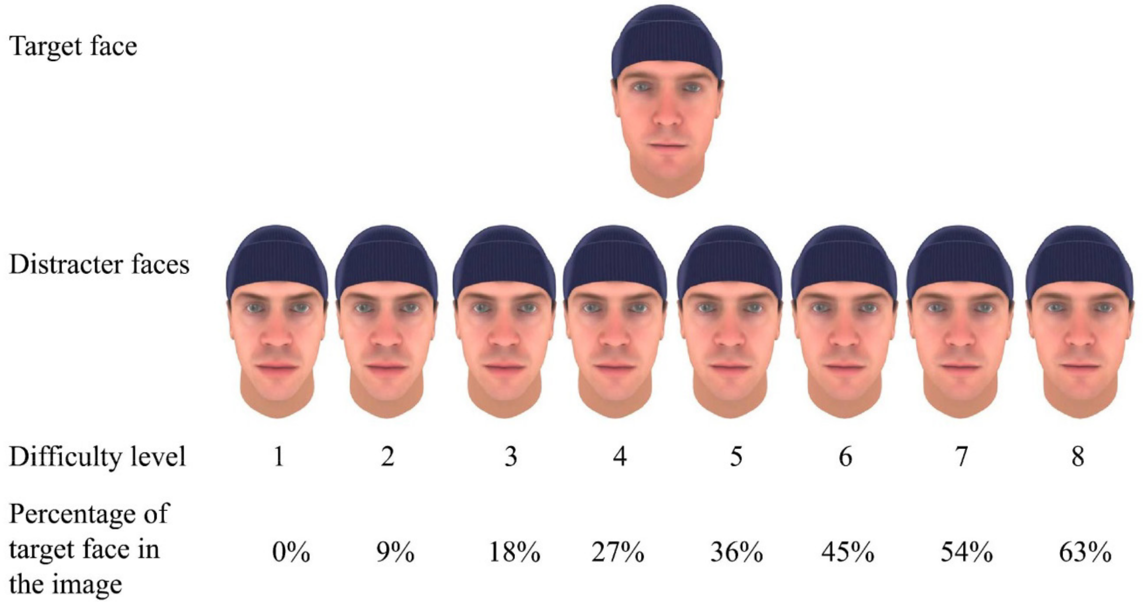

Figure 3. Examples of the face stimuli for the memory training task. Trainees memorised the target face in the top row. To create distracters for the subsequent test phase different amounts of the target were morphed into the images, ranging from Level 1 with 0% of target morphed into the image of the distracter to Level 8 with 63% of the target morphed into the distracter.

At Level 1 (easiest), there was no morphing. For the following levels, increasing amounts of the target face were added to the distracter (Level 2: 9% of target morphed into the distracter face, Level 3: 18%, Level 4: 27%, Level 5: 36% , Level 6: 45% , Level 7: 54%, Level 8: 63%). The more the distracter face contained of the target, the harder it was to discriminate from the originally learned face.

The level of the first test block was always set to three. The level for the following test blocks depended on the percentage of correct responses in the preceding block. However, the steps were larger after the first block than after the remaining five blocks. Table 2 shows the details of how the difficulty level was adapted.

Table 2. Adaptation Steps for the Face Memory Training Task as a Function of the Percentage of Correct Responses

Test block	**Percentage correct in the preceding block**	**Difficulty level in this block**
1st	for all	3
2nd	56% or less	1
	57-61%	2
	62-67%	3
	68-78%	4
	79-83%	5
	84-89%	6
	90-94%	7
	95-100%	8
3rd to 6th	67% or less	next lower
	68-83%	no change
	84% and more	next higher

Note. Adaptation started in the second test block.

All adaptation steps remained within the range of Level 1 to Level 8. In the three test blocks with faces learned the previous day, the levels were not adapted but remained fixed to the levels of the previous day.

2.3.5 Reward Points

Two reward points were granted for each test block with 16 or more hits. At the end of each session, the sum of hits from the highest difficulty level was recorded as best achievement of this session and compared to the best achievements of the previous sessions. If it was the highest score so far, additional seven points were granted.

2.4 Training Facial Speed

2.4.1 Stimuli

All stimuli were taken from the set originally created for the memory training task, i.e. they were not morphed. For each session 45 faces were used with two images each (frontal view and the 30° profile). Each face appeared up to five times within a session.

2.4.2 Training Procedure for Facial Speed

Each training session was comprised of two tasks with 12 blocks each: odd-man-out task (Figure 4, Panel A) and 1-back task (Figure 4, Panel B). For both tasks, each block consisted of 10 trials and perspectives were constant across blocks. At the beginning of each block, a deadline for reaction times was displayed. This deadline was adapted individually with a tracking algorithm (for details, see 2.4.4). Instructions emphasised accurate responses within the deadline. At the end of each task, on overview was displayed to inform about the mean reaction times and accuracies for each block of the task, the mean reaction time over all blocks, the reward points achieved in this session as well as in the training so far.

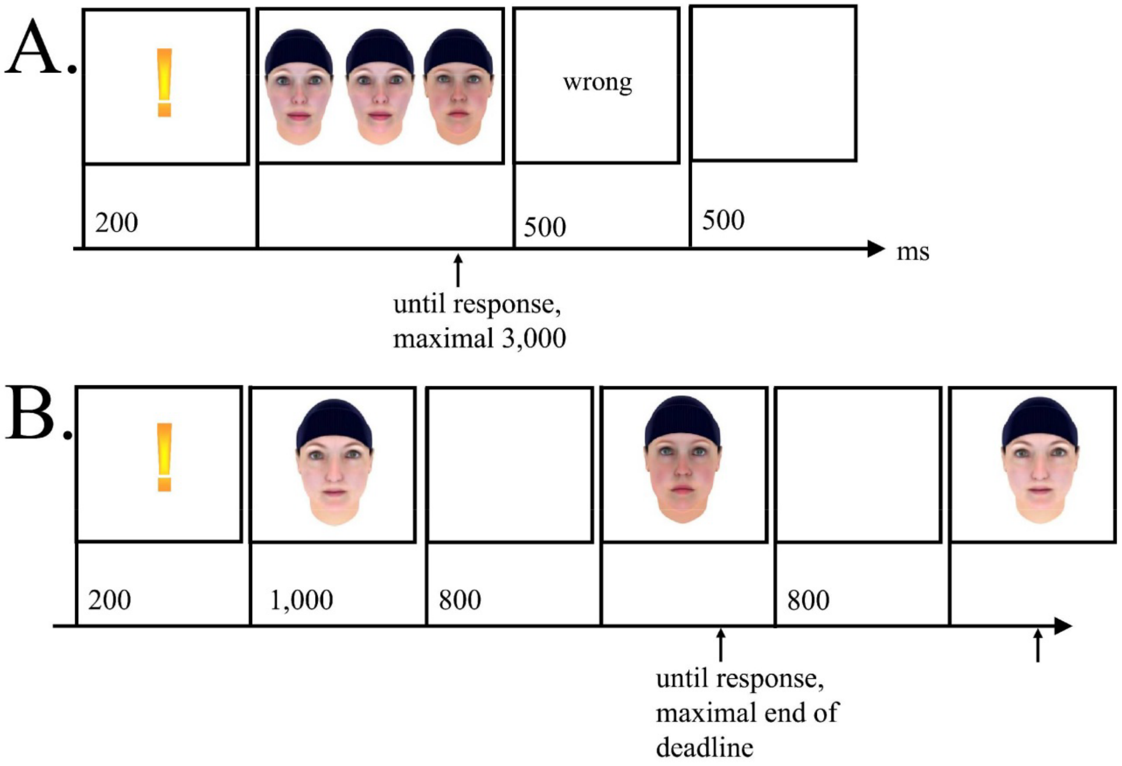

Figure 4. Trial sequences from the facial speed training: odd-man-out task (Panel A) and 1-back task (Panel B).

2.4.3 Tasks for the Facial Speed Training

2.4.3.1 Odd-man-out Task

Each trial of the odd-man-out task began with the presentation of an exclamation mark for 200 ms, followed by three faces presented side-by-side, shown until response or the end of the deadline. Two of the faces were identical and the third face was the odd-man. The odd-man stimulus appeared either on the left or the right side of the screen. This position was randomised from trial to trial. Trainees had to respond by pressing the Alt- or the Alt-Gr-button on the keyboard on the side corresponding to the presentation of the odd-man. Only negative feedback was given. The German words for "incorrect" (falsch), “faster, please” (schneller, bitte), and for “do not guess, please” (bitte nicht raten) appeared as feedback on the screen. The trial ended with a blank screen for 500 ms (intertrial interval).

2.4.3.2 1-back Task

Trials began with the presentation of a centred exclamation mark for 200 ms, followed by the first face, presented for 1000 ms. Following faces stayed on display until the response or until the end of the deadline. Starting from the second face on, participants had to decide whether the current face was the same as the preceding one. They pressed the Alt-button for same and the Alt-Gr-button for different faces. The same feedback as in the odd-man-out task was given. Each trial ended with a blank screen for 800 ms (intertrial interval).

2.4.4 Adaptation

The first session began with a response deadline of 2,000 ms. Responses were considered correct only if the appropriate key was pressed within the deadline. In the first session, the deadline was adapted in large steps to bring everyone to their individual achievement level as fast as possible. Table 3 presents the steps used to adapt the deadline in both training tasks for facial speed. The adaptation steps were largest after the first block. In the following blocks, the steps depended on the percentage of correct responses in the two preceding blocks.

Table 3. Adaptation Steps for the Deadline of the Facial Speed Taks as a Function of the Percentage of Correct Responses

Block	**Percentage of correct responses**	**Adaptation steps of the response deadline**	
		1st session	**Following sessions**
1st	60% or less	+ 400	+ 200
	61-70%	+ 200	+ 100
	71-80%	+ 100	+ 50
	81-90%	0	0
	91-100%	- 200	- 100
2nd-12th	55% or less	+ 240	+ 120
	56-65%	+ 180	+ 90
	66-75%	+ 120	+ 60
	76-85%	+ 60	+ 30
	86-95%	0	0
	96-100%	- 60	- 30

Note. The deadline for the first block of the first session was 2000 ms. In the following sessions, the deadline for the first block was calculated as 200% of the grand average, mean reaction time of the previous session, but with a maximum of 2000 ms.

2.4.5 Reward Points

Two reward points were granted for 90% or more correct responses within the deadline in the preceding two blocks. At the end of each session, the mean reaction time for each task was recorded and compared to the mean reaction times of the previous sessions. If it was the fastest mean reaction time for this task so far, additional five points were granted.

2.5 First Post-Test

Participants from the two intervention groups had finished their training on average 2.8 days before the post-test (range: 0-9 days). This interval did not differ between the training groups, $F < 1.7$. The post-test was an abridged, three-hour version of the test battery administered as pre-test (for details, see Hildebrandt et al., 2010). This test battery was composed of one questionnaire on face cognition skills, 12 face and four object tasks. Two indicators of object cognition measured object perception and two measured object cognition speed. Further, the post-test included one single indicator task each for general cognition (Raven, Court, & Raven, 1979), for immediate and delayed memory (verbal memory IDM3–IDM4 from the Wechsler Memory Scale, Härting, Markowitsch, Neufeld, Calabrese, & Deisinger, 2000), and for mental speed (Finding As, Danthiir, Wilhelm, & Schacht, 2005). At the end of the test, the memory training task and the speed training task, odd man out, were administered. These tasks were not adaptive to performance. The memory task was administered at level three and from the speed task the deadline for fast reactions was removed. For stimulus presentation and response recordings Inquisit 2.0 software was used, except for the training tasks, for which Presentation 13.0 software was used. The PCs were equipped with 17 inch colour screens (with a resolution of 1280 x 1024 pixels and a refresh rate of 85 Hz).

2.6 Second Post-Test

The second post-test was administered 3 months after the first post-test. Trainees finished their training on average 94.5 days before the second post-test (range: 75-99 days). This interval did not differ between the training groups, $F < 1$. The second post-test consisted of the same set of tasks as the first post-test and was conducted with the same apparatus.

2.7 Data Preparation and Analysis

Only correct responses given at least 201 ms after the target onset were analysed. Manifest level performance was scored as proportion of hits for all face perception tasks, all face memory tasks as well as for two indicators of object cognition, one of immediate memory, one of delayed memory, and one of general ability. In contrast, manifest level performance was scored as reaction times for the speed of face cognition tasks, the two remaining indicators of object cognition, and the indicator of mental speed. Reaction times were winsorized (e.g., Barnett & Lewis, 1978). For trials 3.5 *SD*s slower than the individual mean, the latencies were trimmed by a recursive procedure that replaced these outliers with the mean value plus 3.5 *SD*s until there are no values above the mean plus 3.5 *SD*s (for the rationale of this data manipulation compare Herzmann et al., 2008, or Wilhelm et al., 2010). The trimmed reaction times were transformed into inverted latencies by the formula 1000/reaction times in milliseconds in order to obtain a measure of correctly processed trials per second.

2.7.1 Data Analysis at the Manifest Level

Data were analysed to determine group differences, change over time, and interactions. The change of performance over the courses of the training was assessed with regression analyses. The training tasks included in the post-tests were analysed with the between subjects factor group (memory, speed, matched controls). Post-hoc comparisons were Bonferroni corrected (N=2). For repeated measures Huynh-Feldt corrected analyses of variance (Huynh & Feldt, 1976) were performed and uncorrected degrees of freedom and corrected *p*-values are reported. For all other tasks, net effect sizes assessed change over time at the manifest level to control for practice effects due to retest. First, effect sizes were calculated for the three matched groups separately as mean pre-post differences of the indicators divided by the standard deviation at pre-test (Schmiedek, et al., 2010). Next, net effects were calculated as the difference in effect size between each training group and the control group. The interaction of occasion (pre- vs.

post-test) with group (each training group separately vs. control group) served as indicator of statistical significance.

2.7.2 Data Analysis at the Latent Factor Level

The effects of training the two components of face cognition were studied at the ability level with a confirmatory factor analysis modelled in structural equations. This approach allows to tap into the latent constructs, which are not directly measurable, and to explicitly estimate measurement error. At the ability level, face cognition was modelled according to the three factor model by Wilhelm et al. (2010) described above. Autoregressive change models were calculated to analyse the effects at the latent level as suggested by McArdle and Nesselroade (1994). The underlying assumption is that the ability the training aimed at is not observable itself but is a latent factor that can only be measured via indicator variables or tasks (Byrne, 2001). The common variance in these indicators is assumed to be caused by the latent construct. The strength of the relationship between the factor and its indicators is termed factor loading. Changes at the latent level may be analysed by comparing the means over time only if measurement invariance has been established. For models not invariant over time, changes were analysed by regressing dummy variables for the respective training group onto the latent factor. These binary dummy variables coded the regarded group as 1 and all other groups as 0. All analyses at the latent level were computed with Mplus 5 (Muthén & Muthén, 1998-2007). Latent variables were scaled by fixing their variance to one. The influence of the training on the latent variable was evaluated by the critical ratio (*C.R.*). An estimate is significant at the .05 level if the critical ratio exceeds the value of 1.96 (Bollen & Curran, 2006).

Goodness of fit indices assess the fit of the empirical to the theoretical covariance matrices of the specified models (Bollen & Curran, 2006). Because different indices capture different aspects of the model fit more than one measure will be reported. Model fit was evaluated using the chi-square test as well as three descriptive fit indices (Hu & Bentler, 1999): the comparative fit index (CFI), the root-mean-square error of approximation (RMSEA), and the standardised root-mean-square residual (SRMR). The chi-square test relates to the difference between the observed covariance matrix and the theoretical model covariance matrix. The CFI is derived from a comparison of a hypothesised model with the independence model taking the sample size into account; values of .95 or larger indicate acceptable fit. The RMSEA accounts for the error of approximation in the population and is sensitive to model complexity; values less than .05 indicate good fit, and values up to .08 represent reasonable model fit. However, if sample size is small, RMSEA tends to reject true-population models. SRMR is the standardised difference between the observed covariance and the predicted covariance; its value of less than .08 is considered a good fit.

2.7.3 Testing Model Invariance

Training is expected to influence the factor scores indicating intrinsic or quantitative within-person changes (McArdle & Nesselroade, 1994). To compare the amount of those changes in the means of the factor scores structural invariance over time has to be evidenced to render the metric of the means interpretable. Invariance is tested within competing nested models to which constraints are added sequentially. The resulting changes in fit are compared. First, the invariance of factor loadings (configural invariance) over time is tested because the intervention procedure itself could have altered the basic meaning of the common factors (McArdle & Prindle, 2008). Second, metric or weak invariance constrains factor loadings to equality and implies equal regression slopes over time. Metric invariance evidences that the strengths of the relation between specific scale items and the underlying constructs do not differ over time (Meredith & Teresi, 2006). Third, scale or strong invariance is investigated by additionally constraining the intercepts of the factor loadings to equality (Meredith & Teresi, 2006).

When comparing two nested models, their differences in chi squares and in their degrees of freedom test the null hypothesis that the restricted model fits the data as well as the less restrictive model (Bollen & Curran, 2006). If no significant loss of fit is established, this supports the assumption of equality. Contrarily, a significant loss of fit indicates that at least one of the parameters differs. In the literature, further goodness of fit indices are considered for comparisons of nested models. Cheung and Rensvold (2002) recommend that in CFI a value of difference between two models smaller than or equal to .01 indicates that equivalence may be assumed. Meade and colleagues (2008) demand that only for differences smaller than .002 in CFI equivalence may be assumed. However, given the small sample size the latter demand seems too restrictive for this study.

3 *Results of Study 1*

Study 1 was conducted to investigate the effectiveness and the specificity of training procedures for face memory and for facial speed. Further, it was tested whether the component abilities of face cognition are stable over time. The results were analysed with regard to those aims and are presented in the following sections. For reasons of comparison, the effect sizes are all reported as Cohen's *f*.

3.1 Courses of the Training

There were 29 complete sessions for each training procedure. The memory training sessions on day 1 and day 30 were not complete (see above 2.3.2) but added up to a complete session. Fifteen of the memory trainees completed all sessions and the other 4 trainees completed 28 sessions. Eighteen speed trainees completed all sessions, one completed 28 sessions, and one 27 sessions.

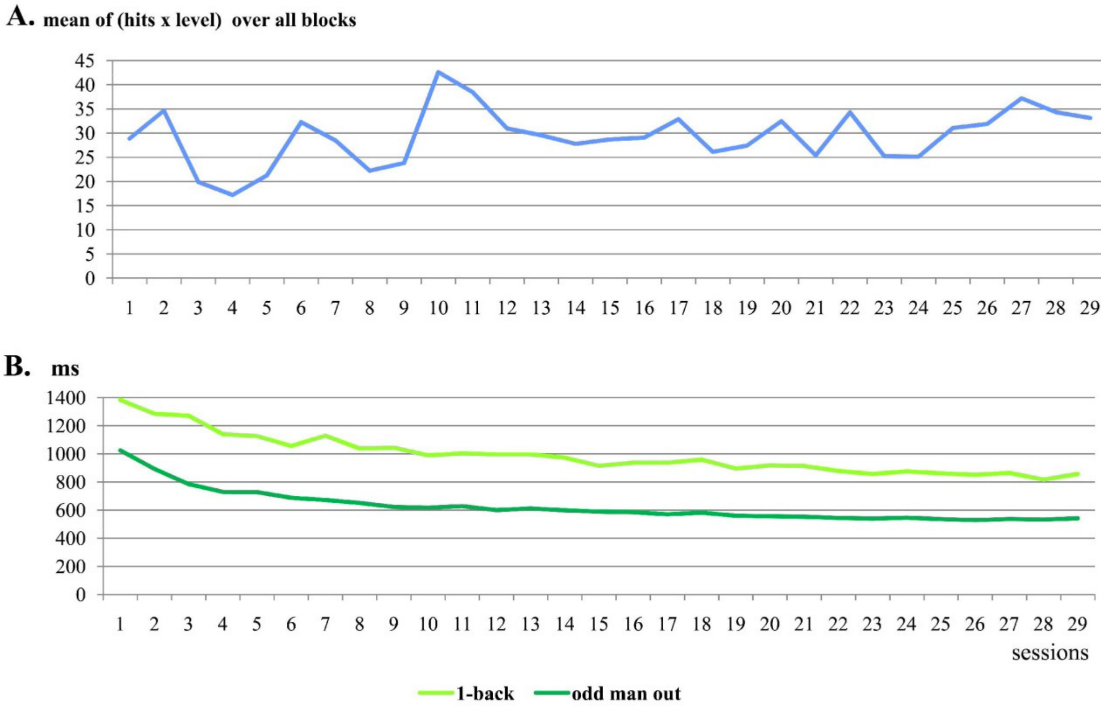

Figure 5. Trainees' performance over the courses of training for face memory (Panel A) and for facial speed (Panel B).

Trainees' performance over the courses (session 1 to session 29) of the two training procedures is depicted in Figure 5. Performance for the memory training was captured as mean of the product of hits and level over all blocks. A marginally significant standardised regression coefficient of $b = .362$ ($t(28) = 2.05$, $p = .05$, $f = .388$) indicated that there was an overall trend for an increase in performance over the course of the memory training itself. The significant standardised regression coefficients in the analyses of the speed training for the odd-man-out of $b = -.912$ ($t(27) = -11.55$, $p < .001$, $f = 2.225$) and for the 1-back task of $b = -.832$ ($t(27) = -7.78$, $p < .001$, $f = 1.495$) indicated reaction times were reduced over the course of the training.

In sum, the analysis of the course of the memory training showed only a marginally significant improvement of performance. Whereas the courses of the speed training tasks indicated that participants increased their performance on both trained tasks.

3.2 First Post-Test

The results of data modelling are based on results of all four groups. All other results include only the data of the three matched groups. Table 4 shows the means and standard deviations for all tasks administered in the first post-test for the three matched groups.

Table 4. Means and Standard Deviations of Behavioural Data for the Three Matched Groups in the First Post-Test

	Practice groups		Control group
	memory	speed	matched
Trained memory task (TRM)	.57 (.10)	.53 (.06)	.62 (.08)
Trained speed task – odd-man-out (TRS)	.75 (.14)	1.09 (.21)	.76 (.20)
Facial resemblance (FP1)	.74 (.06)	.69 (.09)	.75 (.08)
Sequential matching of part-whole faces – condition part (FP2)	.75 (.09)	.68 (.10)	.74 (.06)
Sequential matching of part-whole faces – condition whole (FP3)	.71 (.10)	.67 (.11)	.72 (.13)
Simultaneous matching of spatially manipulated faces – condition upright (FP4)	.75 (.12)	.73 (.12)	.74 (.12)
Simultaneous matching of spatially manipulated faces – condition inverted (FP5)	.68 (.11)	.61 (.10)	.66 (.13)
Acquisition curve (FM1)	.93 (.07)	.90 (.08)	.94 (.06)
Decay rate of learned faces (FM2)	.89 (.08)	.86 (.12)	.91 (.07)
Eyewitness testimony (FM3)	.76 (.09)	.73 (.10)	.76 (.12)
Recognition speed of learned faces (FS1)	.97 (.17)	1.09 (.18)	.91 (.19)
Delayed non-matching of faces to sample (FS2)	.72 (.12)	.84 (.17)	.72 (.20)
Simultaneous matching of faces from different viewpoints (FS3)	.70 (.13)	.92 (.13)	.71 (.22)
Simultaneous matching of upper face-halves – condition aligned (FS4)	.63 (.15)	.78 (.19)	.57 (.13)
Simultaneous matching of upper face-halves – condition non-aligned (FS5)	.69 (.14)	.91 (.12)	.70 (.23)
Simultaneous matching of morphs (FS6)	.86 (.16)	1.06 (.21)	.86 (.24)
Sequential matching of part-whole houses – condition part (OC1)	.78 (.11)	.72 (.10)	.73 (.08)
Sequential matching of part-whole houses – condition whole (OC2)	.72 (.09)	.63 (.11)	.71 (.13)
Delayed non-matching of houses to sample (OC3)	.90 (.15)	1.01 (.20)	.83 (.16)
Simultaneous matching of house morphs (OC4)	.62 (.12)	.73 (.18)	.70 (.33)
Immediate memory (GA1)	.80 (.17)	.74 (.21)	.79 (.15)
Delayed memory (GA2)	.91 (.14)	.89 (.17)	.89 (.13)
General cognitive ability (GA3)	.41 (.19)	.31 (.21)	.38 (.19)
Mental speed (GA4)	1.65 (.21)	1.84 (.25)	1.63 (.29)

Note. Estimated values for accuracy tasks (FP1-5, FM1-3, OC1-2, GA1-3) are mean accuracies and for speed tasks (FS1-6,OC3-4, GA4) inverted reaction times, calculated as 1000/reaction time in ms; SDs are shown in parentheses.

3.2.1 Trained Tasks[2]

The trained memory task was difficult for all participants as indicated by the low performance (*M*s = .57, .53, and .62 for the memory, the speed, and the matched control group, respectively). Performance was above guessing rate of 50% only for the memory and the control group ($t(17) = 2.81$, $p < .05$ memory group and $t(18) = 6.20$, $p < .001$ control group), whereas the speed group performed at chance ($t(18) = 2.10$, $p = .051$). This was observed as a main effect of group, $F(1, 53) = 5.06$, $p < .01$. Pairwise comparisons revealed, however, that the memory group did not differ from the other two groups, *p*s > .29, whereas the speed group performed significantly less accurate only in comparison to the control group, $F(1, 53) = 5.06$, $p < .01$.

In the trained speed task, all participants performed well above guessing rate of 50% (*M*s = .96, .94, and .91 for the memory, the speed, and the matched control group, respectively). The mean reaction times were 1550 ms for the memory group, 1034 ms for the speed group, and 1622 ms for the matched control group. The reaction times of the three groups differed, $F(2, 53) = 14.04$, $p < 0.001$, $f = .728$. Pairwise comparisons revealed that the speed group had significantly shorter reaction times than the memory group, $F(1, 35) = 28.15$, $p < .001$, $f = .867$, and than the control group, $F(1, 37) = 23.18$, $p < .001$, $f = .792$. The memory group and the control group did not differ, $F < 1$.

Both tasks fulfilled the criteria for reliable measures as indicated by high internal consistencies, Cronbach's $\alpha = .812$ for the memory task and Cronbach's $\alpha = .918$ for the speed task. The speed training task correlated highly with the indicators of speed of face cognition from the test battery (all tasks *r*s > .69, *p*s < .01), confirming that this task fitted

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[2] For trained tasks, net effect sizes could not be calculated for they had not been administered at pre-test.

well with the other indicators. The correlations of the memory training task with the indicators of face memory from the test battery were very low (*r*s < .31), indicating that it might not have measured the same ability or that it was much more difficult than the other indicators.

In sum, the memory group did not perform better than the other groups on the trained face memory task. In contrast, the speed group reacted significantly faster on the trained speed task than the other groups.

3.2.2 Face Tasks

Performance results for all tasks are summarised in Table 4. Mean performance was clearly above chance of 50% for all tasks. Figure 6 depicts net effect sizes for the tasks of the first post-test (left row). There were no significant positive net effects for the memory trained group , *F*s < 2.2, and one negative net effect size for the FM2 indicator of face memory, *F*(1, 37) = 6.45, *p* < .05. The speed trained group performed significantly better on all indicator tasks for speed of face cognition, all *F*s(1, 38) > 7.9, *p*s < .01, *f*s > .457. The speed group showed significant negative effect sizes for two face memory tasks, for FM1, *F*(1, 38) = 7.25, *p* < .05, and for FM2, *F*(1, 38) = 5.87, *p* < .05.

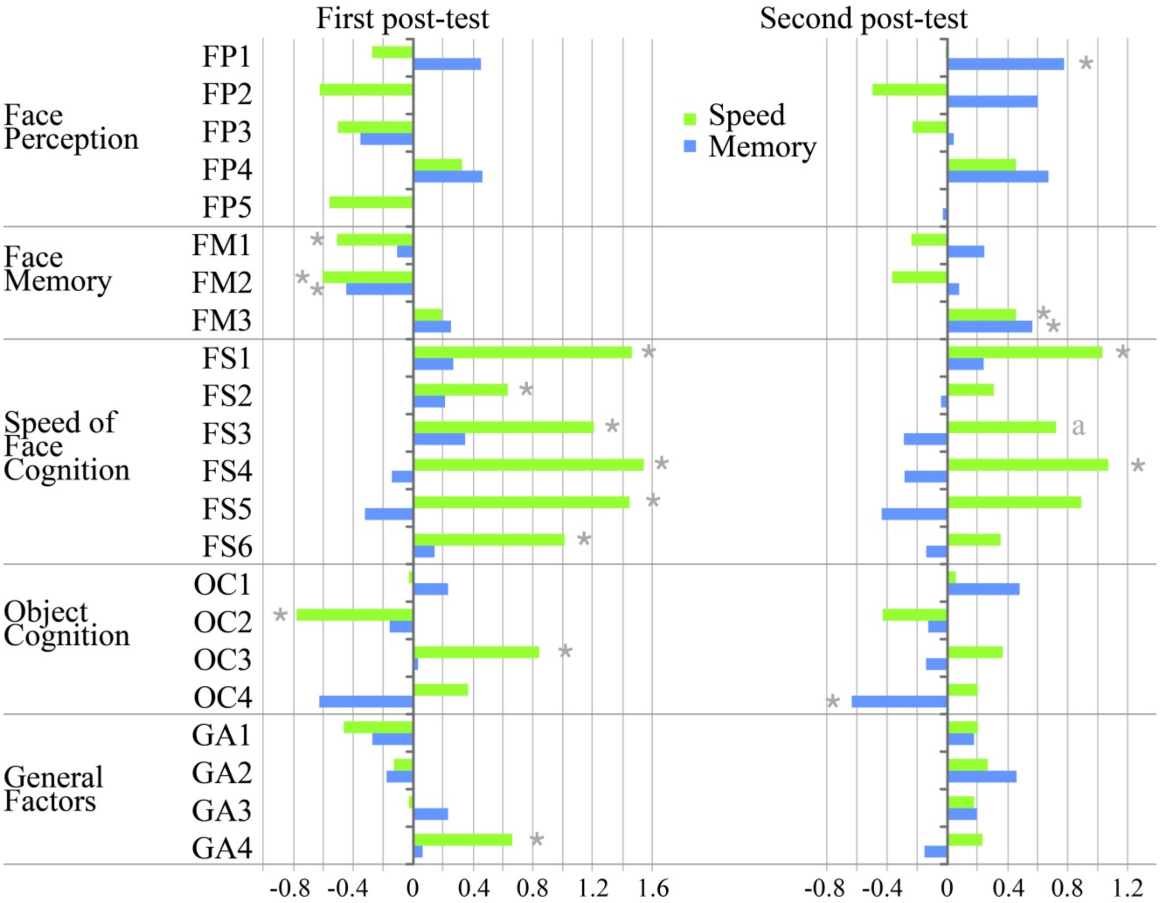

Figure 6. Performance gains from pre-test to first and second post-test as net effect sizes. Bars depict net effect sizes (difference in standardised changes between the experimental and the control group), for the group trained in face memory (blue bars) and in speed of face cognition (green bars). Statistical significance was tested as interactions (p < .05; a: p = .052) between group (training vs. control) and occasion (pre- vs. post-test). FP1 – Facial resemblance; FP2 – Sequential matching of part-whole faces – condition part; FP3 – Sequential matching of part-whole faces – condition whole; FP4 – Simultaneous matching of spatially manipulated faces – condition upright; FP5 – Simultaneous matching of spatially manipulated faces – condition inverted; FM1 – Acquisition curve; FM2 – Decay rate of learned faces 1; FM3 – Eyewitness testimony; FS1 – Recognition speed of learned faces; FS2 – Delayed non-matching to sample; FS3 – Simultaneous matching of faces from different viewpoints; FS4 – Simultaneous matching of upper face-halves – condition aligned; FS5 – Simultaneous matching of upper face-halves – condition non-aligned; FS6 – Simultaneous matching of morphs; OC1 – Sequential matching of part-whole houses – condition part; OC2 – Sequential matching of part-whole houses – condition whole; OC3 – Delayed non-matching of houses to sample; OC4 – Simultaneous matching of house morphs; GA1 – Immediate memory; GA2 – Delayed memory; GA3 – General cognitive ability; GA4 – Mental speed.*

In sum, the results indicated reaction time reductions from pre- to post-test for the speed trained group. There was no increase in performance for the memory trained group.

3.2.3 Object Tasks

There were no significant net effects on the house tasks for the memory trained group, *F*s < 1.97. For both tasks measuring object cognition speed, the net effect sizes for the speed trained group were positive, but only for the indicator OC3 they were significant, $F(1, 38) = 7.46$, $p = .01$, $f = .443$. Further, there was a significant negative effect size for the object perception task OC2 in the speed group, $F(1, 38) = 4.96$, $p < .05$, $f = .361$.

3.2.4 Further Indicators

There were no significant net effect sizes for the indicator tasks of immediate and delayed memory or general cognitive ability, *F*s < 1.2. The speed trained group achieved a significant positive effect size on the task measuring mental speed, $F(1, 38) = 6.22$, $p < .05$, $f = .405$, indicating far transfer from the speed training task to the general mental speed ability.

Summarising the results at the manifest level, only the training of facial speed was effective. It did not transfer to other indicators of face cognition. Further, the facial speed training enhanced performance on all other indicator tasks of speed, that is, on tasks for object speed and for mental speed.

3.2.5 Latent Factor Analysis

Table 5 summarises the fit indices for the models specified for each of the three component abilities of face cognition, which include pre- and post-test data. Generally, error terms were uncorrelated. Some indicators, however, comprised different experimental conditions of the same task (FP2 with FP3, FP4 with FP5, and SFC4 with SFC5). For these indicators correlation of error terms was theoretically expected and, thus, it was specified.

Table 5. Competing Structural Equation Models Investigating Training-Induced Changes of Face Perception, Face Memory, and Speed of Face Cognition at the Latent Factor Level

Model	**Specifications**	χ^2	**df**	***p***	**CFI**	**RMSEA**	**SRMR**
Perception							
1	Baseline (worst case) 2 factors uncorrelated	48.99	32	.028	.950	.067	.054
2	2 factors, post-test regressed on pre-test	no convergence					
3	2 factors, post-test regressed on pre-test @1	81.77	34	.000	.860	.109	.125
4	**2 factors, indicators correlated over time**	**52.49**	**29**	**.005**	**.931**	**.083**	**.121**
5	2 factors, all factor loadings constrained	76.03	36	.000	.883	.097	.191
6	2 factors, loadings and intercepts constrained	80.89	39	.000	.862	.101	.184
Memory							
1	Baseline (worst case) 2 factors uncorrelated	41.85	13	.000	.949	.137	.058
2	2 factors, post-test regressed on pre-test	41.85	13	.000	.949	.137	.058
3	2 factors, post-test regressed on pre-test @1	42.15	14	.000	.951	.131	.069
4	2 factors, indicators correlated over time	13.21	11	.280	.996	.041	.055
5	**2 factors, all factor loadings constrained**	14.40	**13**	**.346**	**.998**	**.030**	**.078**
6	2 factors, loadings and intercepts constrained	42.29	16	.00	.954	.118	.147
Speed							
1	Baseline (worst case) 2 factors uncorrelated	184.37	62	.000	.927	.129	.045
2	2 factors, post-test regressed on pre-test	184.37	62	.000	.927	.129	.045
3	2 factors, post-test regressed on pre-test @1	187.05	63	.000	.926	.129	.055
4	2 factors, indicators correlated over time	93.51	57	.002	.978	.074	.051
5	**2 factors, all factor loadings constrained**	**103.33**	**62**	**.001**	**.976**	**.075**	**.071**
6	2 factors, loadings and intercepts constrained	148.67	68	.000	.952	.100	.070

Note. CFI = comparative fit index; RMSEA = root-mean-square error of approximation; SRMR = standardised root-mean-square residual; bold demarcates the final models.

3.2.5.1 Latent Ability Model for Face Perception

The baseline model for perception (Model 1) had an acceptable fit. Regressing the factor for the post-test on the pre-test (Model 2) led to a non-converging model. Whereas, constraining this regression to one (Model 3) rendered a model fit worse than the baseline. Correlating the tasks over time (Model 4) increased the model fit meaningfully, as confirmed by a significant $\Delta\chi^2$-test of 29 corresponding to Δdf = 5 (see Bollen & Curran, 2006). Configural invariance was thereby established. Further constraining the factor loadings to equality (Model 5) led to an unacceptable model fit, as confirmed by a significant $\Delta\chi^2$-test of 24 corresponding to Δdf = 7, and had to be rejected. For face perception the same number of factors could be established over time but not the same pattern of loadings. Metric invariance was rejected, and Model 4 was the final model (Figure 7).

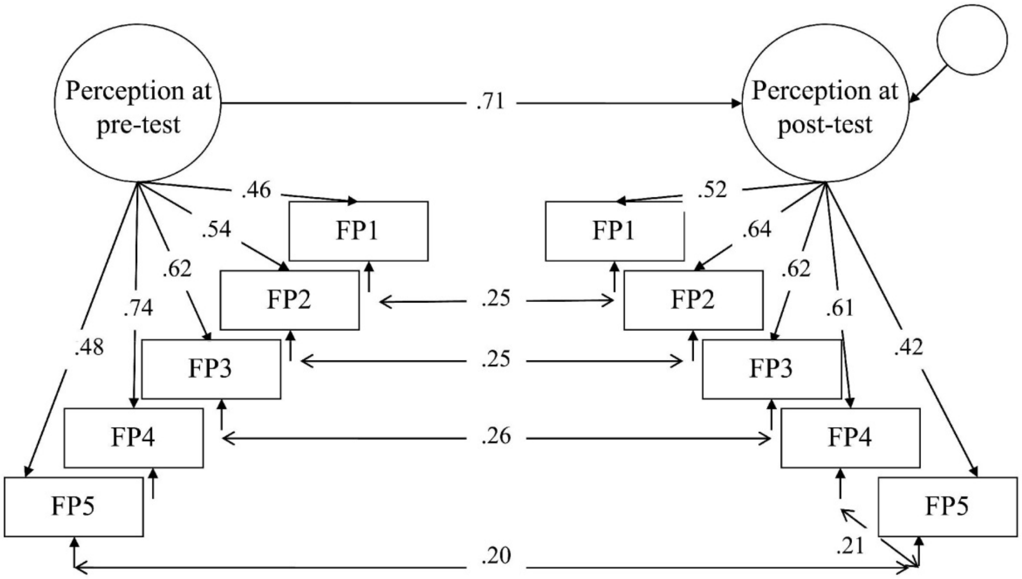

Figure 7. Final measurement model for the component ability face perception (Model 4). FP1 = Facial resemblance; FP2 = Sequential matching of part-whole faces – condition part; FP3 = Sequential matching of part-whole faces – condition whole; FP4 = Simultaneous matching of spatially manipulated faces – condition upright; FP5 = Simultaneous matching of spatially manipulated faces – condition inverted. Only coefficients that were statistically significant at α = .05 are depicted.

The standardised factor loadings were substantial (.42-.74). The autocorrelations of the unique scores over time were significant except for the task FP4. *Simultaneous matching of spatially manipulated faces* task comprises two conditions of one assignment: upright (FP4) and inverted (FP5). These conditions were significantly correlated within the post-test, *C.R.* = 2.13. The regressions the memory and the speed training group onto the post-test factor of the final model were not significant, *C.R.*s < 1, indicating that neither of the training procedures influenced face perception.

3.2.5.2 Latent Ability Model for Face Memory

The baseline model (Model 1) for memory did not fit the data. Regressing the post-test factor on the pre-test (Model 2) did not ameliorate the model fit nor did constraining the regression of the post-test onto the pre-test to one (Model 3). Correlating the tasks over time (Model 4) increased the model fit meaningfully, as confirmed by a significant $\Delta\chi^2$-test of 29, corresponding to Δdf = 3. Constraining the factor loadings to equality (Model 5) did not decrease the model fit significantly (not significant $\Delta\chi^2$-test of 1, Δdf = 2). Therefore, metric invariance may be assumed.

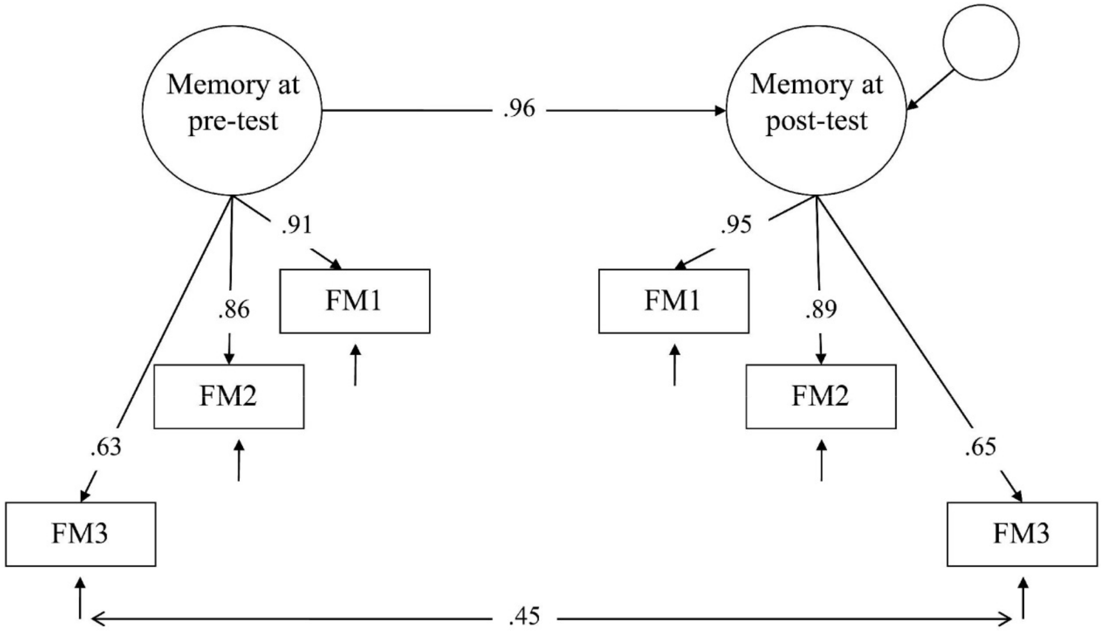

Figure 8. Final measurement model for the component ability face memory (Model 5). FM1 = Acquisition curve; FM2 = Decay rate of learned faces 1; FM3 = Eyewitness testimony. Only coefficients that were statistically significant at α = .05 are depicted.

Further, constraining the intercepts of the indicators to equality (Model 6) led to an unacceptable model fit (significant $\Delta\chi^2$-test of 28, $\Delta df = 3$). Strong invariance must be rejected. In a model with unequal intercepts, the difference in the latent means of the two time points might be confounded with differences in the scale and origin of the latent variables. For such cases Byrne et al. (1989) proposed comparing latent means under partial invariance. This procedure assumes that the non-invariant item will not affect the latent means comparison to a great extent. But it is important to keep in mind that such results are explorative and might reflect an attribute of the sample rather than describe the theoretical model. There were only three indicator tasks for the latent memory factor. It was therefore refrained from proceeding in the suggested explorative fashion and eliminating one of them, since this would change the model strongly. Model 5 was the final model (Figure 8). All standardised factor loadings were substantial (.63-.95). The autocorrelations of the unique scores over time were significant only for the *Eyewitness testimony* task but not for the tasks *Acquisition curve* and *Decay rate of learned faces*. The regression of the memory training group[3] onto the post-test factor for face memory was not significant, *C.R.* < 1, indicating that memory training did not influence the latent component ability of face memory.

3.2.5.3 Latent Ability Model for Facial Speed

For the facial speed factor, the baseline model (Model 1) did not fit the data. Regressing the speed factor for the post-test on the pre-test (Model 2) left the model fit unchanged as did further constraining that regression to one (Model 3). Correlating the

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[3] Regression of the speed training group was negative and significant, *C.R.* = -3.34, *p* = .001, indicating that the speed trained group scored lower on the post-test than the other groups.

tasks over time (Model 4) increased the model fit meaningfully, significant $\Delta\chi^2$-test of 94, Δdf = 6. Additionally, constraining the factor loadings to equality (Model 5) could be accepted, as implied by a not significant $\Delta\chi^2$-test of 10, Δdf = 5. In Model 6, the intercepts of the indicator tasks were constrained to equality, but this resulted in a significant loss of fit, $\Delta\chi^2$-test of 45, Δdf = 6. Six tasks served as indicators for the facial speed factor. Testing partial invariance (Byrne, et al., 1989) revealed that even if the three tasks with the most differing intercepts between pre- and post-test were excluded from the equality constraint and allowed to be estimated freely, there was still a significant loss of model fit, $\Delta\chi^2$-test of 25, Δdf = 3. Therefore, this explorative method was abandoned and the strictly confirmatory Model 5 was accepted as the final model (Figure 9).

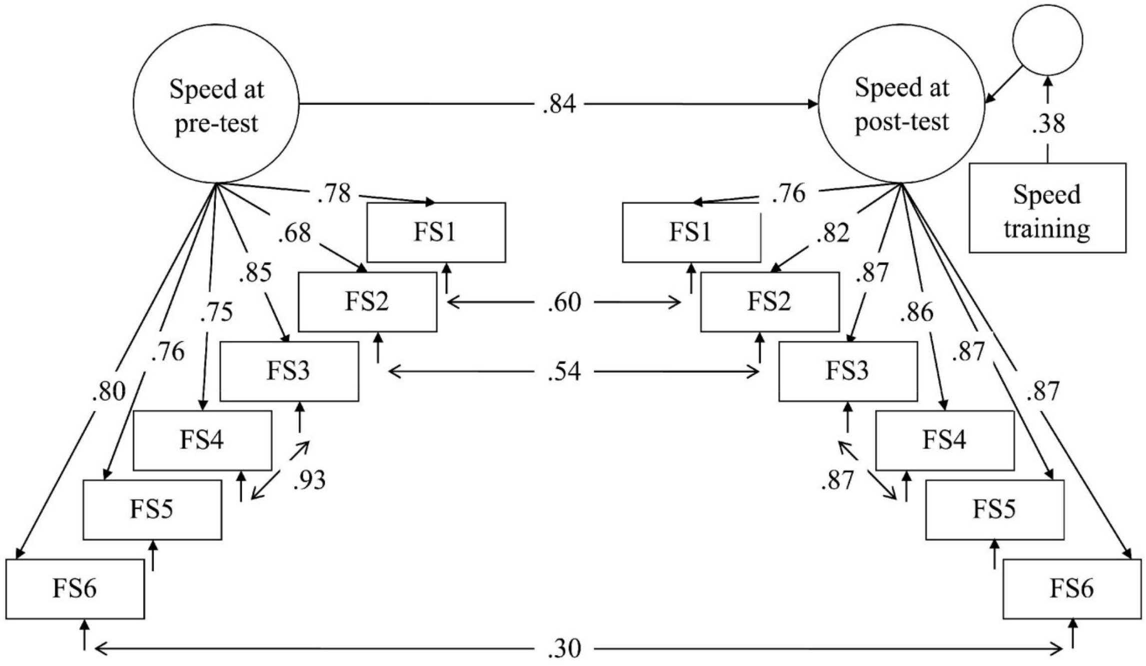

Figure 9. *Final measurement model for the component ability facial speed (Model 5). FS1 = Recognition speed of learned faces; FS2 = Delayed non-matching to sample; FS3 = Simultaneous matching of faces from different viewpoints; FS4 = Simultaneous matching of upper face-halves – condition aligned; FS5 = Simultaneous matching of upper face-halves – condition non-aligned; FS6 = Simultaneous matching of morphs. Only coefficients that were statistically significant at α = .05 are depicted.*

All standardised factor loadings were substantial (.68-.87). The autocorrelations of the unique scores over time were significant for three of six tasks. For the *Simultaneous matching of faces from different viewpoints* (FS3) task, there was a strong trend for significance, *C.R.* = 1.93, *p* = .054. The *Simultaneous matching of upper face-halves* task comprises two conditions of one assignment: align (FS4) and non-align (FS5). These conditions were significantly correlated within each test occasion, *C.R.*s = 33.24 and 68.88 for pre- and post-test, respectively. In this model, the definitions of the factor measures on both occasions were explicitly defined to be the same and, hence, it was possible to interpret the regression of the post-test onto the pre-test as a stability coefficient over time for the test variable (McArdle & Nesselroade, 1994). The reduction of fit when constraining the intercepts to equality implied the intercepts differed between pre- and post-test[4]. The regression of the speed training group[5] onto the post-test factor for facial speed was significant, *C.R.* = 7.75, indicating that the members of the facial speed training group scored higher on the post-test than the other participants.

3.2.5.4 *Three Factor Model of the Post-Test*

A model of the post-test including all three component abilities of face cognition had an acceptable fit, χ^2(96, N = 118) = 158.36, CFI = .950, RMSEA = .074, SRMR = .063. All factor loadings were substantial (.38-.94) as were the correlations of the component abilities (.37-.78). The regression of the group that trained memory onto the memory factor was not significant, *C.R.* = -.33, *p* > .5. Contrarily, the regression of the

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[4] Exclusion of participants trained on speed from the pre-post-model of facial speed still led to the rejection of equal intercepts. The model fit for weak measurement invariance was reasonable, χ^2(51, N = 181) = 78.14, CFI = .981, RMSEA = .074, SRMR = .057. This result indicates that the differences in intercepts were not solely caused by the speed training.

[5] Regression of the memory training group was not significant, *C.R.* = -.12, *p* = .908, indicating that the memory training did not influence the latent factor for facial speed.

group that trained speed onto the speed factor was significant, *C.R.* = -5.92, $p < .001$, indicating that the speed training influenced the targeted ability[6].

3.2.5.5 Omnibus Model

The omnibus model (Figure 10) was composed of all three component abilities at pre- and at post-test. The model fit was assessed according to Hair et al. (2010). This model had an acceptable fit, $\chi^2(382, N = 118) = 583.34$, CFI = .928, RMSEA = .067, SRMR = .172.

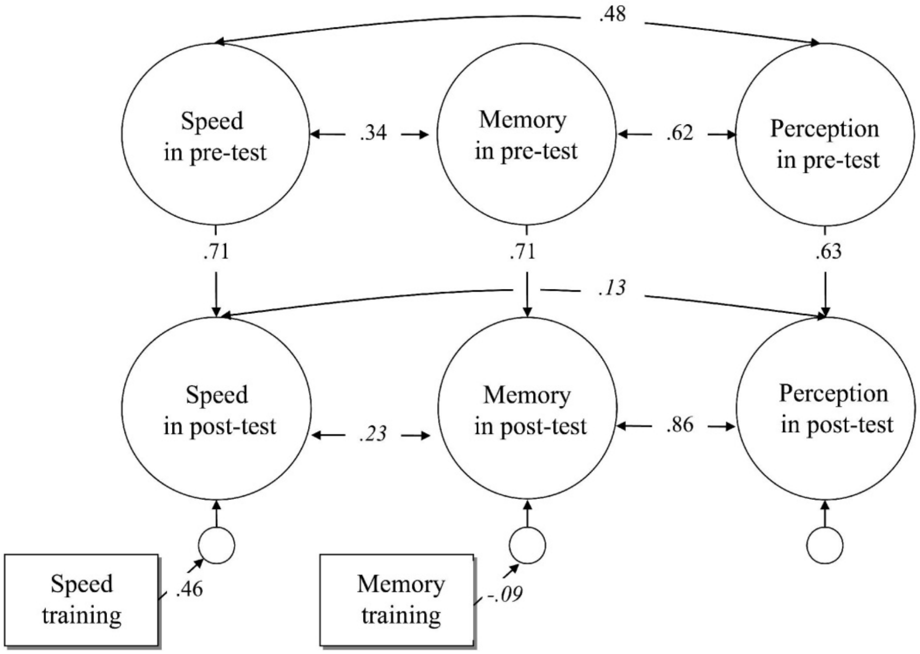

Figure 10. Omnibus model comprising pre- and post-test measurements for all three component abilities of face cognition with both training groups included as dummy variables. Unique scores were autocorrelated over time. Coefficients that did not reach statistical significance at α = .05 are italicised.

The factor loadings were correlated over time. The loadings of the pre- and post-factors for face memory and speed of face cognition showed considerable communalities (.54-.91), whereas the loadings of the perception factor were weaker (.44-.71). The

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[6] All other regressions of group onto the abilities at post-test were not significant, *C.R.*s < 1.46, *p*s > .13.

correlations of the latent ability factors at pre-test and the correlation of perception with memory at post-test were substantial (.34-.62). The latent speed factor at post-test did not correlate with the other component abilities, *C.R.*s < 1. The regression of the memory group onto the latent component ability of face memory was not significant, *C.R.* = -1.51, $p > .1$. In contrast, the regression of the speed group onto the latent component ability of facial speed was meaningful, *C.R.* = -5.58, $p < .001$, indicating that the speed training influenced the targeted ability[7].

3.2.5.6 Further Testing Specificity of Facial Speed Training Effects

To find out more about the influence of the training of facial speed on speed of object cognition, the three factor model of the post-test was extended. A new latent factor for speed of object cognition was added to the model. The new model with four correlated latent factors was estimated, namely face perception, face memory, speed of face cognition, and speed of object cognition. The model fit the data well, $\chi^2(95, N = 118) = 156.26$, CFI = .955, RMSEA = .074, SRMR = .057. All factor loadings were substantial (.38-.95). The correlation of the two speed components for faces and for objects was high ($r = .97$), thus, strongly indicating that the two factors might capture the same domain-general ability. The regressions of the speed group onto the two speed factors were significant, *C.R.* = 4.35, $p < .001$, for facial speed and *C.R.* = 3.54, $p < .001$, for object speed[8], indicating that the speed training influenced both these abilities.

To test the assumption of a domain-general speed ability, a competing model was estimated. In this model, the two latent speed factors were merged into one. The fit of the

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[7] Regression of the speed group onto the memory factor at post-test was significant, *C.R.* = 2.05, $p < .05$. All other regressions of group onto the abilities at post-test were not significant, *C.R.*s < 1.39, *p*s > .20.

[8] All other regressions of group onto the ability factors were not significant, *C.R.*s < 1.47, *p*s > .14.

model with the domain-general latent speed factor was comparable to the model with two speed factors, $\chi^2(98, N = 118) = 159.21$, df = 98, $p < .000$, CFI = .955, RMSEA = .073, SRMR = .057. The not significant $\Delta\chi^2$-test of 2.95, Δdf = 2, indicated that the differentiation between facial speed and object speed was not needed.

3.2.5.7 Summary of the Latent Factor Analyses

At the latent level, there was no increase of performance due to the memory training. In contrast, enhanced performance was shown for the speed training. This training procedure also enhanced performance on a latent factor for object speed.

3.3 Second Post-Test

For the trained tasks, change of performance between the first and the second post-test was analysed with repeated measures on the within factor test occasion (first post-test, second post-test) and the between factor group (memory, speed, matched controls). For all other tasks, the effect sizes were calculated as changes of performance from pre-test to the second post-test. Statistical significance of net effect sizes was tested as interactions between group (training vs. control) and occasion (pre- vs. second post-test).

3.3.1 Trained Tasks

For the memory training task, there was a trend for better performance at the first than at the second post-test, $F(1, 53) = 3.65$, $p = .061$, $f = .262$, which was qualified by an interaction of test occasion with group, $F(2, 53) = 4.87$, $p < .05$, $f = .429$. Pairwise comparisons revealed that the matched controls performed significantly better on the first than on the second post-test, $F(1, 53) = 8.76$, $p < .01$, $f = .406$, whereas the performance of the other two groups did not change over time, Fs < 2.8. There was no main effect of group, $F < 1.1$.

For the speed training task, mean reaction times did not differ between the two test occasions, $F < 1$. However, there was a main effect of group, $F(2, 54) = 9.82$, $p < .001$, $f = .603$, and an interaction of group with test occasion, $F(2, 54) = 8.78$, $p < .001$, $f = .570$. Pairwise comparisons revealed that in the first post-test the speed group reacted faster than the other two groups, $F(1, 35) = 33.95$, $p < .001$, $f = .984$, compared with the memory group and $F(1, 37) = 24.35$, $p < .001$, $f = .810$, with the matched controls. In the second post-test, only the difference towards the memory group was still significant, $F(1, 35) = 15.03$, $p < .001$, $f = .655$. Reaction times of the memory group and the matched controls differed neither in the first nor in the second post-test. Comparing the two test occasions, the control group reacted faster in the second than in the first post-test, $F(1, 54) = 6.11$, $p < .05$, $f = .336$, whereas the speed group reacted significantly slower on the second post-test, $F(1, 54) = 11.68$, $p < .001$, $f = .465$. All other post-hoc comparisons were not significant, Fs < 1.9.

In the second post-test, correlations of the memory training task with other indicators of face memory were all very low (rs $< .22$) and not significant. The correlations between the speed training task and the indicators of speed of face cognition from the test battery were strong (all tasks rs $> .54$, ps $< .01$), though weaker than in the first post-test.

3.3.2 Face Tasks

The net effect sizes of the face tasks in the second post-test are depicted in Figure 6 (right row). On indicator of face perception, FP1, there was a significant positive net effect size for the memory group, $F(1, 37) = 4.70$, $p < .05$, $f = .357$. On the FM3 indicator of face memory, both groups had significant positive net effect sizes, $F(1, 37) = 6.93$, $p < .05$, $f = .433$, memory group and $F(1, 38) = 4.70$, $p < .05$, $f = .352$, speed group. These effect sizes indicated better performance on these tasks in the second post-test compared with the pre-test. Though for all speed of face cognition tasks the effect sizes for the speed group were positive, only two of them were still significant, Fs(1, 38) = 8.84 and 6.38, ps < .05, fs = .482 and .410, for FS1 and FS4, respectively. A third task, FS3, displayed a trend, $F(1, 38) = 4.04$, $p = .052$, $f = .326$.

3.3.3 Object Tasks

The memory group had a significant negative net effect size on the indicator of object speed OC4, $F(1, 37) = 4.49$, $p < .05$, $f = .348$. There were no further significant net effect sizes on any of the house tasks (compare Figure 6), Fs < 1.88.

3.3.4 Further Indicators

There were no significant net effect sizes on the indicator tasks for general cognitive ability, immediate and delayed memory, or mental speed (compare Figure 6), Fs < 1.8.

3.3.5 Summary of Results of the Second Post-Test

On the second post-test, both groups achieved a significant positive effect size on one of three indicators of face memory. The net effect sizes of the speed group on all indicators of facial speed and of object speed were still positive though only two were still significant.

4 Discussion of Study 1

Two training procedures, which are based on the three factor model of face cognition (Wilhelm, et al., 2010), were developed and tested. To bypass retest effects at the manifest level, net effect sizes were regarded, thereby taking any changes in performance due to test repetition into account. At the latent level, the effects of training were investigated by regressing the training groups onto the latent abilities and retest issues were irrelevant here. The results showed only effects of the speed of face cognition training but no effects of the memory training. The speed training did not change performance on the other factors of face cognition. However, it led to shorter reaction times on all indicators of speed, indicating lack of specificity. The model of face cognition established by Wilhelm et al. (2010) was replicated and extended over time, confirming that it measures long-lasting skills. In the next sections, effectiveness of the training procedures, specificity of these effects for face cognition, aspects of validity, and finally the replication of the three factor model with its extension over time will be discussed in turn.

4.1 Effectiveness

The effectiveness of the two training procedures was tested at three different levels: first, within the trained task itself, second, within other indicator tasks for face cognition, and third, at the latent ability level. The results of the memory training will be considered first and of the speed training second.

4.1.1 Effectiveness of the Memory Training

Despite a trend for improvement on the trained face memory task over the course of training, there was no positive transfer to any other face memory task in the first or in the second post-test. This lack of effects might be attributed to several reasons: First, the training procedure might have been too short to induce significant levels of change because of costs caused by strategy switching. Such switching costs may compensate or even exceed the training-induced progress (Goldman, et al., 1989; Klauer, 2001; Kliegl & Philipp, 2006; Kliegl, et al., 2001; Maichle, 1992). The trend for increasing performance over the courses of the training could point in this direction. Prior to the training, participants had their own strategies for memorising faces, which they might abandon in favour of new training specific strategies. But if the duration of the intervention is too short, then the new strategies will not have enough time to fully develop. Kliegl and Philipp (2006) even argue that a training might be insufficient and that better results should be achieved by developing a special interest for the training aim and turning it into a hobby thereby augmenting the amount of practice.

Second, the employed training procedure might have been too demanding. The adaptation was based on increasing resemblance between target and distracter, resulting in an increasing perceptual demand in addition to the higher demand on memory. The training task used artificial faces that might be less distinct than photographs of different individuals. Kliegl and colleagues (2001) found that such stimuli increased task difficulty because they were less variant. The low scores of all groups on the memory training task in the two post-tests point in this direction (*M*s = .571 and .548 for the first and second post-test, respectively). The difficulty levels in this study had been piloted. Three of nine participants who worked through the first session already reached Level 5. Therefore, Levels 6 to 8 were included to prevent ceiling effects during training.

Third, the applied indicator tasks for face memory might not be adequate anymore in the retest setting. The identical test battery was administered at pre-test as well as at first and second post-test causing two changes: The new faces for controlled learning had already been memorised previously and all faces had been seen before rendering even the distracters familiar during retests. Therefore, the tasks in the post-test might have measured different aspects of face memory than in the pre-test. Three tasks measured face memory. For two of these tasks, the autocorrelations between test occasions were not significant, thus hinting that their definitions might have changed over time. One task measured the acquisition of new faces, but at post-test these faces were not new anymore. The other task measured recognition performance of these learned faces after 2.5 hours, but here these faces had been retained over several months and practiced more often. Interestingly, the third task correlated well over time. This task was designed as an incidental task to measure recognition of distracters after a single exposure. In the retest setting, the task became rather explicit. The target faces had already been seen as distracters at each test occasion and more importantly they had served as targets during the previous test, thus, confounding the definition of the task itself.

According to Bryne and Stewart (2006), changes in the definition or content of a task lead to non-equivalence at the level of configural invariance testing. In this study, configural invariance for the model of the latent ability of face memory could be assumed. This finding implies that the same construct had been measured at pre- and post-test. Therefore, even if the retest situation altered the definitions of the indicators, long-term memory processes were measured at the latent level. Literature on formation of memories for faces confirms that it is a continuous process (Mangels, Manzi, &

Summerfield, 2009; Ramon, Caharel, & Rossion, 2011) as indicated by an increasing N250 component for repeatedly presented faces (Churches, Damiano, Baron-Cohen, & Ring, 2012; Itier & Taylor, 2004; Kaufmann, et al., 2009; Tanaka, Curran, Porterfield, & Collins, 2006) or other objects of expertise (Krigolson, Pierce, Holroyd, & Tanaka, 2009; Scott, Tanaka, Sheinberg, & Curran, 2006, 2008). Burton, Jenkins, and Schweinberger (2011) interpret the process of familiarisation as a transition from relying mainly pictorial codes to relying on structural codes for recognition. Similar implications for encoding follow from the prototype theory of face recognition (Benson & Perrett, 1993; Burton, et al., 2005). The more often a face is seen the more information can be extracted and the better or the more situation-general the prototype becomes. Therefore, it is assumed that even in this retest setting memory for faces had been measured.

Last but not least, it might be impossible to train the memory for faces because it is already an ability everyone practices everyday in real life and therefore performs at the maximum level, as some prior studies concluded (Elliott, et al., 1973; Malpass, 1981; Sporer, 1991). As the latter studies found no training effects on face memory the lack of significant training results may not be that surprising. Future training, applying different methods, may demonstrate better effects of training face memory, though the results of the study presented here and its methodological thoroughness are not encouraging in this regard. The results from face memory training might be seen as a kind of null result, and indeed it is impossible to rule out that future studies applying different training methods will demonstrate the intended effects. However, it is just as likely that such training results will not be upcoming precisely because enhancement of face memory through training is difficult or impossible to achieve compared to the amount of everyday experience.

Summarising, changes of face memory after training were investigated at the manifest and at the latent level. The approach chosen was methodologically very sound, however, the presented results provided no evidence for the efficacy of training face memory.

4.1.2 Effectiveness of the Speed Training

The speed group reacted faster than the other two groups on the speed training task administered at first and second post-test. Further, it achieved significant gains in performance on all facial speed tasks in the first post-test and retained the better performance on two out of six indicators in the second post-test. Because the tasks in the post-test differed from the trained tasks, this finding demonstrates near transfer. At the latent level, effectiveness of the speed training was again demonstrated in the omnibus model with pre- and post-test data.

These findings provide unique evidence for plasticity of speed of face cognition within healthy middle-aged individuals. In this respect, they replicate and extend earlier findings of training speeded responses (Bourne, Healy, Pauli, Parker, & Birbaumer, 2005) and of performance enhancement through training of speed of processing in aged population (Gunther, Schafer, Holzner, & Kemmler, 2003; Smith et al., 2009; Willis et al., 2006; Yang & Krampe, 2009; Yang, Krampe, & Baltes, 2006; for review see Ball, Edwards, & Ross, 2007). In the Advanced Cognitive Training for Independent and Vital Elderly (ACTIVE) study, elderly participants trained their speed of processing. For evaluation, a performance-based functional measure of everyday speed of processing was used and evidenced gains in the targeted ability (Willis, et al., 2006). Training of speed and accuracy of processing auditory information significantly enhanced processing speed (Smith, et al., 2009). Even simple retest learning enhanced the speed of processing. The first study comprised a pre-test, six retests, and a post-test and showed practice-induced performance gains in speed of processing (Yang, et al., 2006). The second study examined the persistence of these results after 8 months and found still increased performance on the measure of speed of processing (Yang & Krampe, 2009). In another study, elderly participants successfully trained on a continuous date comparison task intended to enhance their information processing speed (Gunther, et al., 2003).

Since statistical significance gives only the probability of finding the observed difference by chance, the effect sizes for the facial speed training were compared to those of training studies on speed of face processing. The effect size for the training of processing speed was $f = .44$ in the investigation of Smith et al. (2009) and $f = .15$ in the study by Willis et al. (2006). For the facial speed training, the effect sizes[9] on six indicators of facial speed were medium to large (range: .35-.98, mean: .63) and five of them were larger compared to the ones reported above. This might be due to the younger age of participants in the facial speed training as compared to the other studies (cf. Yang & Krampe, 2009).

Two other studies did not control for retest effects. The study by Gunther et al. (2003) had no control group and administered two runs of the same Trail Making Test both in the pre- and in the post-test. The effect sizes were $f = 1.14$ directly after the

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[9] For purposes of comparison to the literature the effect sizes here are not net effects (cf. Figure 6), but calculated for changes in reaction time when contrasting the training groups (i.e., speed vs. memory trainees).

intervention and *f* =1.05 for the 5-months follow-up. The retest training in the study by Yang & Krampe (2006) resulted in an effect size of *f* = 2.35 after taking the same test 8 times. Therefore, these effect sizes are related to simple task specific improvements. For the facial speed training here, this compares best to the effect sizes for tasks practiced during the training itself: for odd-man-out task *f* = 2.22 and for 1-back task *f* = 1.50. Overall, the effect sizes of the facial speed training were comparable to the ones reported in the literature.

These results may reflect that the speed training induced a trade-off between accuracy and speed. At the manifest level, significant findings of lower accuracies in combination with faster reactions of the speed group would point towards such a trade-off. In two memory tasks of the first post-test, the effect sizes were negative and significant (compare Figure 6) indicating reductions of accuracy in the speed group after the training. On one of those two tasks however, there was a significant negative effect size for the memory trainees' performance, too. Therefore, there seems no reason to assume that both groups' lower performance on this task should present a trade-off effect induced by the speed training. Further for both tasks, the reaction times did not differ significantly between the groups, indicating that the speed group did not perform faster on these tasks than the other matched groups. At the latent level, lower scores of the speed group on the accuracy-based factors in combination with a higher score on the reaction time-based factor would hint at trade-off. After the training, the speed group improved on facial speed and scored lower on face memory in two of four models calculated. However, its scores on face perception did not change. Thus, these results do not support the notion that the effects of the speed training are solely due to a trade-off, and it deems safe to assume that some portion of the changes represents the intended training effects.

Further, the training of speed of face cognition generalised to a different kind of face stimuli. During training, artificially generated faces were used, whereas the test battery utilised photographs. This transfer effect corresponds to the findings in other studies that also showed that training on artificial stimuli generalised to photographs (DeGutis, et al., 2007; DeGutis, et al., 2011).

In summary, the speed training procedure tested here reduced reaction times as intended. Training gains were evidenced at the manifest and at the latent level. The effect sizes achieved were large. Further, near transfer was demonstrated on independent indicators of facial speed and with another kind of stimuli. These findings parallel the literature on training speed of processing and reflect the plasticity of facial speed for middle-aged adults.

4.2 Specificity

Since, as discussed above, only the training of facial speed was effective, the specificity will be discussed only for this training procedure. As intended, the training of facial speed significantly influenced the respective latent ability factor. While the facial speed training did not influence the ability of face perception, it lowered performance on face memory in the omnibus model and in the model for face memory incorporating pre- and post-test. However, there was no significant influence of the speed training on the ability of face memory in the model incorporating only the post-test data for the three facial factors and the extended model with the object speed factor. The influence of the speed training on face memory emerged only after controlling for individual differences at pre-test. As discussed above, this effect is attributed to a trade-off between accuracy and speed, and it presents a small and unspecific influence of the training. Interestingly, the trade-off occurred even though the instruction emphasised both speed and accuracy during training and even though only for accuracy levels exceeding 90% reward points were granted and the time pressure increased.

A further indication of specificity would come from regarding net effect sizes for indicator tasks of immediate and delayed memory, general cognitive ability, and mental speed. There were no significant interactions between group and measurement time point for the indicators of immediate and delayed memory and of general cognitive ability. Thus, there was no reason to assume that these abilities had been influenced by the speed training. However, further analysis of specificity revealed that facial speed training enhanced speed of object cognition as indicated by significant improvement of performance on the factor for object speed. Wilhelm et al. (2010) found facial speed to be strongly correlated with mental speed but nonetheless a distinct ability. Two further studies that explored the specificity of facial speed report different results. One study found a perfect correlation between the speed of face cognition and the speed of processing for emotional expressions, whereas the latter factor correlated only moderately with object cognition (Hildebrandt, Schacht, Sommer, & Wilhelm, 2012). More importantly, the other study showed that the speed measures of face cognition reflect the same ability as speed measures for houses (Hildebrandt, Wilhelm, Herzmann, & Sommer, 2012). The authors concluded that this ability captures the speed of processing complex visual stimuli. The present study confirms and extends these findings by demonstrating that training aimed at facial speed also enhances performance for processing non-face stimuli. These findings suggest that the training program used here affected something that is important for fast reactions to complex stimuli but not specific to face cognition. Thus, the speed training developed and tested here enhances a more general speed for perception and recognition of complex stimuli. Indeed, it would be very interesting to find out whether facial speed training also enhances the speed of processing for emotional expressions.

Some cognitive aging studies also demonstrated that training of speed of processing transfers to other cognitive abilities. Ball, Edwards, and Ross (2007) re-analysed the data from six studies on training speed of processing with older adults. They found that training-induced improvements transferred to everyday abilities as well as to driving performance. The authors further report two interesting findings. First, trainees with initial deficits of processing speed obtained higher gains than those without deficits. Second, interventions, which were adaptive to trainees' performance all along, achieved larger effect sizes than the interventions that combined standardised procedures with adaptive ones. Edwards, Delahunt, and Mahncke (2009) combined data from two studies to examine the impact of speed of processing training on the risk of driving cessation. Their analyses suggest that older drivers with speed of processing difficulties may delay driving cessation by training their processing speed ability. In the study by Gunther et al. (2003), a broadly aimed computer-assisted training improved information processing speed in older adults and it also improved learning of verbal material and reduced interference tendency, a cause of memory loss. Training on speed and accuracy of processing auditory information improved the targeted abilities and transferred to untrained standardised measures of memory and attention (Smith, et al., 2009). Most interestingly, trainees' self-reports suggested that the training gains may be behaviourally significant. In the latter two studies, trainees practiced on sets of broad-based exercises, therefore, the transfer of improvements cannot be directly attributed to the speed of processing training. However, other studies find no transfer of speed of processing training to measures of activities of daily living (compare Ball et al., 2002; Willis et al., 2006). The authors of the latter studies suggest that the advantaged nature of the samples might have caused ceiling effects on measures of everyday cognitive abilities and, thus, left no room to show improvement through training. This reasoning is concordant with the finding of larger training-induced gains in trainees with deficits of the trained ability (Ball, et al., 2007).

Summarising, cognitive aging research indicates that speed of processing may transfer to measures of everyday functioning specifically for those persons with decline of their speed of processing. The effects of facial speed training investigated here improved speed for face cognition, speed for object cognition, and enhanced performance on a mental speed task with letters as stimuli. Therefore, the indication of the speed training was reassessed and extended to the ability of perceiving and recognising complex stimuli swiftly. It remains for future research to find out more about the transfer effects from the training developed here to measures of everyday functioning. But if this intervention can help enhance the speed of processing in general or prevent it from age-related decline, then there are obvious practical applications for such a training.

4.3 Validity

The following paragraphs describe how the different aspects of validity were realised in this study. Validity was evaluated only for the facial speed training since only this training was effective.

Convergent validity refers to training the performance aimed at. Here, convergent validity was demonstrated by the finding of faster reaction times in the speed group than in the other groups on the trained speed tasks administered during the post-tests.

Faster performance of the speed group on all facial speed tasks from the test battery evidenced criterion validity. These tasks are based on theories of face cognition and have been shown to be reliable indicators of the latent ability factor of facial speed (Herzmann, et al., 2008).

Construct validity requires that the underlying ability needed to perform the trained task is influenced by the intervention and not merely the task specific performance. Here, structural equation modelling was used to analyse the influence of training at the latent ability level. Effects were assessed in a model for the trained component at pre- and post-test, in an integrated model consisting of all three component abilities of face cognition at post-test, as well as in the omnibus model comprising pre- and post-test data of all three component abilities. As intended, the speed training procedure enhanced performance for speed of face cognition at the latent ability level within all models tested.

Discriminant validity demands that the effects of training do not influence other abilities apart from the one aimed at. Discriminant validity was tested by analysing the effects of training on the other components of face cognition ability and on indicator tasks for transfer. The speed training did not influence face perception but it reduced performance on face memory to some extent. Further, it did not change performance on the indicator tasks for immediate and delayed memory, or for general cognitive ability. However, the speed training reduced reaction times on indicator tasks for speed using other stimuli than faces, displaying unintended far transfer effects. Thus, discriminant validity for the facial speed training was not evidenced.

4.4 Replication and Extension in Time

The third aim was to replicate the three factor model of face cognition and to extend it over time by including two test occasions in one model. Since the same participants were tested again, a replication of the model using this within design would indicate that the three factors of face cognition represent abilities which are stable over time.

The measurement model established by Wilhelm et al. (2010) and applied to different age groups by Hildebrandt et al. (2010) was replicated with the post-test data. Further, for each of the three component abilities of face cognition a two factor model with the latent variables for the pre-test and the first post-test was established. For the two trained component abilities metric invariance over time was established. Strong invariance, which would have allowed for comparison of means at the latent level, had to be rejected. The reduction of fit when constraining the intercepts to equality implied that the intercepts differed between pre- and post-test. An intercept expresses the value of a task when the influence of the latent variable is zero (Byrne & Stewart, 2006; Meredith & Teresi, 2006). For both factors, some standardised intercepts at post-test were smaller than those at pre-test (memory: one, speed: four) and some larger (memory: two, speed:

two). Unequal intercepts are interpreted as diverging difficulty levels (Byrne, et al., 1989; Chan, 2000; Lanning, 1991). These differing intercepts indicate that the difficulty for single indicators changed from pre-test to post-test.

The replication of the three factor model in combination with its extension in time further confirms that abilities were measured at the latent level. Weiner (2000) defines ability as an internal attributional factor for success that is stable in time in contrast to unstable or temporary factors like effort, difficulty, or luck. One year passed between the pre-test and first post-test. For all three components of face cognition, configural invariance was supported, indicating that over the span of 12 months participants conceptualised these constructs in the same way (Cheung & Rensvold, 2002), that is as factors composed of the same indicators (Meredith, 1993). This finding allows a further implication. It confirms that regarding the results of the study by Hildebrandt et al. (2010) as pre-test values was suitable.

4.5 Conclusions from Study 1

The methodological and technical approach of Study 1 was sophisticated in concept, realization, and data analysis compared with other studies on training face cognition (cf. Chiller-Glaus, 2009; Malpass, 1981). However, effectiveness of face memory training could not be evidenced. Publications of studies that do not find effects of training add to the overall context of interpreting the efficacy of training literature. Having full knowledge of previous face cognition training procedures and their results (significant and not significant ones) will help future researchers to identify the mechanisms for plasticity and understand their limitations.

Training the component ability speed of face cognition significantly enhanced the ability aimed at and reached large effect sizes. The finding of a trade-off between accuracy and speed was not consistent; nevertheless it gives rise to the assumption that some portion of the effects might be due to the trade-off. This training also enhanced the speed of object cognition and mental speed. In line with previous research, this training procedure generalised to other speed indicators substantiating far transfer (Ball, et al., 2007; Hildebrandt, et al., 2012) and was reassessed. This is the first study to show that training facial speed with an unsupervised, computer-based intervention can improve the targeted ability and extend to gains in speed for perception and recognition of complex visual stimuli.

4.6 Open questions leading to Study 2

An open question, leading to the next study was, what has been influenced by the speed training? Specifically, did this training procedure speed up the response selection processes or did it shorten the motor processes involved in response?

III Study 2

1 Introduction Study 2

Study 2 was conducted to replicate the findings of Study 1 in an abbreviated re-training design and to localise the psychophysiological underpinnings affected by the training of facial component abilities. Each training procedure served as an experimental condition and at the same time as the control condition for the other training procedure. In two tasks, ERPs were recorded. The matching task aimed to elucidate whether the speed training influenced the pre-motor processes or the motor preparation process. The priming task aimed to investigate the effects of both training procedures on specific stages of face memory, namely recognition of individual faces and activation of semantic information associated with a face. The following sections describe the two experiments, the ERP components used, and the hypotheses.

1.1 Matching Task

This task aimed to investigate, which processes were affected by the speed training, using a 1-back matching paradigm with faces and houses as stimuli. The time between target onset and reaction execution encompasses all visual and cognitive processes as well as the choice and preparation of the motor execution of the reaction itself. The electrophysiological component lateralised readiness potential (LRP) allows bisecting this time interval into pre-motor and motor preparation processes and was used here to pinpoint the locus of training-induced changes.

1.1.1 A Measure of Time Demand for Pre-Motor and Motor Preparation: LRP

The LRP is considered a chronometric measure of the activation of reaction-related processes triggered by the preparation of movement (Coles, 1989; Dejong, Wierda, Mulder, & Mulder, 1988; Eimer, 1998). Reaction preparation for responses by hand is characterised by a more negative scalp distribution over the contralateral hemisphere than over the ipsilateral hemisphere (Luck, 2005). The LRP is recorded over the motor cortices and computed as a difference wave of the contralateral minus the ipsilateral recording site for each hand and experimental condition separately. A negative deflection indicates the correct response hand was activated. Dividing the time before reaction execution into two components renders discrimination of the pre-motor processing from the motor processing possible (Masaki, et al., 2004; Osman, Moore, & Ulrich, 1995). The first component is analysed in the time segment from the stimulus presentation to the onset of the response activation and is averaged locked to the stimulus (S-LRP). The S-LRP is considered to represent the time demand for the pre-motor processes of response selection (Leuthold, Sommer, & Ulrich, 1996). The second component is analysed locked to the reaction (LRP-R) and starts after the selection of the response hand. It is regarded as an indicator of the time needed for the motor programming of reaction execution (Osman & Moore, 1993).

This property of chronometric differentiation makes the LRP a particularly suited measure for localising and interpreting the changes induced by the training of facial speed. A shortening of the S-LRP interval for the speed trained group could be interpreted as influence of this training on the reaction selection processes. On the other hand, a shortening of the LRP-R interval would imply that the training-induced changes are at the level of motor programming processes.

The interesting question was which cognitive subprocess taking place before the reaction execution would be affected by the speed training. Just like for the speed training in Study 1, studies imposing time pressure found faster reaction times (Osman et al., 2000; Sangals, Ross, & Sommer, 2004; van der Lubbe, Jaskowski, Wauschkuhn, & Verleger, 2001). Additionally, time pressure resulted in earlier onsets of the LRP-R component. Osman et al. (2000) used a letter flanker task with a blocked instructional manipulation, which stressed either accuracy or speed and found that only the later portion of the LRP was affected. In another study, varying amounts of time pressure were investigated with different tasks (van der Lubbe, et al., 2001). The results once again revealed that time pressure shortened the LRP-R interval whereas the S-LRP remained uninfluenced. In a dual-task setting, time pressure was imposed on the response to the second task also yielding a shortening effect on the motor processing (Sangals, et al., 2004). However, all these results were gained in studies using a single-session design. Therefore, these effects on the LRP might be explained by a voluntarily induced shift of response strategy.

Training aims to produce changes which are far-reaching and go beyond such voluntary shifts of response strategies. Sangals et al. (2007) trained participants over five sessions in a dual-task procedure. Their training shortened reaction times for both tasks and reduced task interferences. Contrarily to the single-session studies, the training led to earlier onsets of the S-LRP, whereas the LRP-R was not affected. This finding indicates that practice effects due to training as opposed to shifts of response strategy affect response selection but not motor programming. Therefore in the present study, the speed training was expected to influence the pre-motor processes indexed by the S-LRP interval but not the motor programming indexed by the LRP-R. It was hypothesised that the onsets of the S-LRP will be earlier in the speed trained group than in the memory trained group.

1.1.2 Memory Training as Control Condition

Some studies show dissociations between performance and psychophysiological data with effects that remain covered at the behavioural level and become evident only at the psychophysiological level, for example studies of the relationship between eye movement and attention or memory (Beck, Peterson, & Angelone, 2007; Hayhoe, Bensinger, & Ballard, 1998; Ryan, Althoff, Whitlow, & Cohen, 2000) or ERP studies (Heil & Rolke, 2004; Schweinberger, Pfutze, & Sommer, 1995; Stahl, Wiese, & Schweinberger, 2010). Though, there were no behavioural effects of the memory training in the post-test neither at the manifest nor at the latent ability level in Study 1, there was a marginally significant increase in performance on the trained task over the course of the training. In Study 2, re-training might again cause changes not strong enough to be measured as significant behavioural effects. Nevertheless, these changes might significantly affect the ERPs. The LRP component was used to investigate, which changes of cognitive processes contribute to the measured reaction time reduction induced by the speed training. The memory training had not caused a significant reduction of reaction times in Study 1. It was not expected to affect reaction times in Study 2, and there was no reason to expect it would influence the psychophysiological underpinnings of reactions. Hence, the memory training was regarded as a valid control condition for the investigation of the effects of the speed training on the LRP.

1.2 Priming Task

This task aimed to elucidate the effects of training on specific stages of face processing using the repetition priming paradigm. Two face memory components that are commonly elicited in this paradigm are closely related to specific processing stages, namely the N250r to the recognition of individual faces and the N400 to the activation of semantic information related to faces. Group differences in the amplitudes and latencies of these two components after re-training were of special interest here. These two components as well as further face related ERP components will be introduced in the following sections and hypotheses on the effects of training will be developed.

1.2.1 A Measure of Individual Face Recognition: N250r

The N250r, or early repetition effect, is largest at the inferior temporal electrodes as a stronger negativity for primed compared to unprimed faces around 200 to 350 ms after stimulus onset (Pfütze, Sommer, & Schweinberger, 2002; Schweinberger, Huddy, & Burton, 2004). It is more pronounced over the right than over the left hemisphere and not elicited by semantically associated faces (Schweinberger, et al., 1995). Converging evidence from inverse dipole localisation techniques in ERP and fMRI studies implicates the fusiform gyrus as the generator of N250r (Gauthier, et al., 1999; Henson, Shallice, & Dolan, 2000; Schweinberger, Pickering, Jentzsch, Burton, & Kaufmann, 2002). The amplitude increases with familiarity (Herzmann, Schweinberger, Sommer, & Jentzsch, 2004), but it diminishes when different pictures of the same person are presented (Schweinberger, Pickering, Jentzsch, et al., 2002) indicating some degree of image specificity (Burton, et al., 2011). However, stretching of famous face images did not affect the N250r (Bindemann, Burton, Leuthold, & Schweinberger, 2008). Studies that do not employ repetition-priming report similar results, namely that familiar faces elicit larger negative brain waves (N250) at inferior temporal sites as compared with unfamiliar faces (Abdel Rahman, 2011; Gosling & Eimer, 2011; Tanaka, et al., 2006). Therefore, the N250r/N250 is taken to index the activation of memory representations for faces (Engst, Martin-Loeches, & Sommer, 2006; Herzmann, et al., 2004; Pfütze, et al., 2002; Schweinberger & Burton, 2003), which have their theoretical equivalent in the face recognition units of the model by Bruce and Young (1986).

More differentiated assumptions about the processes adding up to elicit this component stem from recent studies. Literature on face cognition reports a reduced N250r for unfamiliar faces (Begleiter, Porjesz, & Wang, 1995; Boehm, Klostermann, & Paller, 2006; Herzmann, et al., 2004; Pfütze, et al., 2002). Schacter (1990) proposed one exposure to an unfamiliar stimulus might initiate a pre-semantic structural representation and thus leave a residual trace. The N250r to new faces has been suggested to reflect the initial encoding of a face recognition unit or the activation of a just developed structural representation (Itier & Taylor, 2004; Neumann, Mohamed, & Schweinberger, 2011). An experiment with backward masking revealed that besides structural perceptual codes also representations from long-term memory contribute to the N250r (Dörr, Herzmann, & Sommer, 2011). Taken together, it currently seems most likely that the N250r is an index of individual face recognition (Bindemann, et al., 2008; Schweinberger, 2011) encompassing the activation of existing representations for familiar faces as well as of new representations from perceptual codes for novel faces.

1.2.2 A Measure of Access to Person-Related Semantic Information: N400

The second component, the N400 or the late repetition effect, arises as a higher parietocentral positivity or lower negativity following 300 to 600 ms after the stimulus presentation for primed faces as compared to unprimed faces (Boehm, Sommer, & Lueschow, 2005; Schweinberger, 1996; Schweinberger, Pickering, Jentzsch, et al., 2002). Familiar faces elicit a lager N400 than new faces (Pfütze, et al., 2002; Schweinberger, Pickering, Burton, & Kaufmann, 2002), and personally familiar faces larger than famous faces (Herzmann, et al., 2004). The N400 arises even under conditions of high perceptual load, for example, when task-irrelevant faces are presented (Neumann, et al., 2011; Neumann & Schweinberger, 2008). Further, the N400 is found when target faces are primed by associated faces (Schweinberger, 1996; Schweinberger, et al., 1995) or with the person's name (Schweinberger, 1996). Thus, this modality-independent component is assumed to index the access to person-related, semantic knowledge in long-term memory (Paller, Gonsalves, Grabowecky, Bozic, & Yamada, 2000; Ramon, et al., 2011). Theoretically, this corresponds to the activation of semantic representations of familiar faces (Bentin & Deouell, 2000; Eimer, 2000; Pfütze, et al., 2002) in the person identity nodes in the model by Bruce and Young (1986) or the semantic information units in the interactive activation model (Burton, et al., 1990).

1.2.3 Further Face Related Components

Although, N250r and N400 were the main dependent variables other psychophysiological measures associated with face cognition were also analyzed. The following sections describe these three ERP components: P100, N170, and P300.

1.2.3.1 A Measure of Pictorial Encoding: P100

The P100 component is most prominent at lateral occipital electrodes, peaks between 100 and 130 ms after stimulus onset, and is sensitive to visual processing, for example stimulus colour or brightness (Luck, 2005; Paulus, Homberg, Cunningham, Halliday, & Rohde, 1984; Plendl et al., 1993). Faces may elicit stronger responses of the P100 than other stimuli (Herrmann, Ehlis, Ellgring, & Fallgatter, 2005; Itier & Taylor, 2002). However, the finding of face selectivity for the P100 is not consistent in the literature (e.g., Thierry, Martin, Downing, & Pegna, 2007; for review, see Rossion & Jacques, 2008). Basic emotion recognition has also been shown for this component (Meeren, van Heijnsbergen, & de Gelder, 2005). Desjardins and Segalowitz (2009) suggest that the face-elicited P100 might reflect an early pictorial encoding stage.

1.2.3.2 A Measure of Structural Encoding: N170

The N170 component is elicited by visual stimuli at the occipito-temporal electrodes between 100 and 200 ms after stimulus onset. It is regarded as a correlate of the general structural analysis of stimuli (Bentin, Allison, Puce, Perez, & McCarthy, 1996; Schendan, Ganis, & Kutas, 1998; Stekelenburg & de Gelder, 2004). It is larger for faces than for other stimuli (Guillaume et al., 2009). Specifying a single overarching account for the characteristics of the N170 has proven difficult, because of the diverging results on three major issues. First, it is still unresolved whether the N170 exhibits specificity for faces or whether the lager amplitude is rather a result of visual expertise (Bentin, DeGutis, D'Esposito, & Robertson, 2007; Carmel & Bentin, 2002; Rossion, Curran, & Gauthier, 2002). Second, some studies find repetition modulates the N170 (Herzmann & Sommer, 2010; Itier & Taylor, 2004; Jemel, Pisani, Calabria, Crommelinck, & Bruyer, 2003). However, other studies find no effects of repetition (Cooper, Harvey, Lavidor, & Schweinberger, 2007; Eimer, 2000; Engst, et al., 2006). Third, though the N170 was not affected by familiarity in numerous studies (Bentin & Deouell, 2000; Eimer, 2000; Tanaka, et al., 2006), other studies did find such effects (Caharel et al., 2002; Herzmann & Sommer, 2010; Jemel, et al., 2003). Experimentally induced top-down modulations might explain some of the influence of familiarity on the N170 component (Caharel, Fiori, Bernard, Lalonde, & Rebai, 2006; Caharel, et al., 2002). In the studies cited above, the N170 was elicited in very different paradigms. Different stimuli (degraded vs. non-degraded, famous vs. studied, photographs vs. Mooney faces) and different experimental settings (immediate vs. delayed priming, familiarity task vs. Joe task) were used. This methodological variability is one possible reason for the divergence in the patterns of results (Itier & Taylor, 2004).

1.2.3.3 An Additional Measure of Memory Processing: P300

The P300 is characterised by a slow positive wave maximal at central parietal electrode sites with a maximum between 300 and 800 ms after stimulus onset following a task-relevant stimulus. The P300 component is independent of stimulus modality (Kutas, McCarthy, & Donchin, 1977) and has been associated with various cognitive processes, for example, context updating (Fabiani, Karis, & Donchin, 1986), chronometry of stimulus evaluation (Leuthold & Sommer, 1998; McCarthy & Donchin, 1983), memory functions (Potter, Pickles, Roberts, & Rugg, 1992), or even with cognitive ability (Stelmack & Beauchamp, 2006). However, the exact processes indicated by the P300 are still under debate (e.g., Verleger, 1997; for a review, see Fabiani, Gratton, & Federmeier, 2007). This association to memory functions makes the P300 an interessting marker for the present study. The P300 component is related to attention and context maintenance for subsequent memory processes (Polich, 2007). Its amplitude is larger for items subsequently remembered than for not remembered items (Fabiani, Gratton, Chiarenza, & Donchin, 1990; Paller, Kutas, & Mayes, 1987; Sanquist, Rohrbaugh, Syndulko, & Lindsley, 1980) and it is also increased for familiar faces compared to unfamiliar faces (Henson et al., 2003; Joyce & Kutas, 2005; Paller, et al., 2003). Studies investigating memory processes with the remember/know paradigm categorise items as remembered if they are remembered with semantic details and as known in the absence of such details. Items categorised as remembered elicit lager P300 amplitudes than items categorised as known (Wiese & Daum, 2006; Wolk et al., 2006).

In the present study, the P300 served as an additional marker for face related memory processes. The memory training aimed at enhancing these processes and was expected to increase P300 amplitudes. On the other hand, the speed training should not influence any memory related processes, and thus, P300 amplitudes were not expected to be affected.

1.2.4 Expected Effects and Control Conditions

Herzmann et al. (2010) studied the relationship between component abilities of face cognition and face specific ERP components measured as latencies and as amplitudes. In their study, the component abilities that are based on accuracy measures, face perception and face memory, were not distinguishable and, consequently, were collapsed into one accuracy factor.

Herzmann et al. found no significant correlations between P100 and the component abilities of face cognition. The only significant result for the N170 was its negative correlation with the latency of the accuracy factor. P100 is thought to index early pictorial encoding and N170 the structural encoding. Both training procedures require pictorial and structural encoding and were, therefore, not expected to affect the P100 or the N170 differently. As discussed above however, some studies found effects of familiarity on the N170. Familiarity did not play any role in the speed training, but decisions in the memory training might have been based on familiarity. Hence, effects of familiarity on the N170 may become evident as shorter latencies for the memory group than for the speed group.

Table 6. Excerpt of Standardised Regression Weights for Analyses of ERP Components and Face Cognition Abilities from Table 3 by Herzmann et al. (2010)

		Ability Factor	
		Face Speed	Face Accuracy
N250r	Latency	-.12	-.33*
	Amplitude	.46***	.41**
N400	Latency	-.23	-.48**
	Amplitude	.35**	.31*
P100	Latency	.14	.07
	Amplitude	-.01	.09
N170	Latency	.19	-.30*
	Amplitude	-.10	.08

*Note. P300 was not included in this study. *p < .05, **p < .01, ***p < .001.*

As Table 6 shows, both ability factors, face speed and face accuracy, were positively correlated to the amplitudes of N250r and N400 (Herzmann, et al., 2010). However, only the ability of face accuracy was significantly negatively correlated to the latencies of these ERPs. Four distinct combinations of training-induced effects on the latencies and amplitudes of these two ERP components can be deduced (see Table 7).

Table 7. Possible Training-Induced Effects on the N250r and N400: Depending on which Training Affects these Components, no Exhaustiveness Being Intended

Effective Procedure	on N250r/N400[a]	
	Latency	Amplitude
none	mem = spd	mem = spd
spd and mem	mem < spd	mem = spd
only spd	mem = spd	mem < spd
only mem	mem < spd	mem > spd

Note. mem = memory group; spd = speed group.

[a] *Both components displayed the same pattern of correlations in the study by Herzmann et al. (2010) and are, therefore, expected to be affected by training in the same way.*

First, if both training procedures are not effective, neither latencies nor amplitudes of the N250r and N400 ERPs will differ between the groups. Second, if both procedures are effective to the same extent, the negative correlation of the latencies of the two ERPs with the face accuracy factor should result in shorter latencies in the memory group than in the speed group. Because both ability factors were positively correlated with the amplitudes of the ERPs and to a similar extent (N250r: r = .46 and .41, N400: r = .35 and .31, for face speed and face accuracy, respectively) the amplitudes are not expected to differ. Third, if only the speed training is effective, this should result in larger amplitudes for the speed group than for the memory group. The latencies should not differ in this case. Fourth, if the memory training was the only one effective, the latencies of the two ERPs should be shorter in the memory group than those of the speed group. Additionally, the amplitudes of both ERPs should be larger in the memory group than those in the speed group.

Depending on the pattern of results, it might be possible to discern which training affected the ERP components related to face cognition. Therefore, both training procedures were regarded as experimental conditions as well as valid control conditions for each other.

1.3 Aims and Hypotheses

As a precondition, the re-training in Study 2 was expected to replicate behavioural findings reported in Study 1. The aims of this study were threefold:

1. Localise the psychophysiological underpinnings affected by the speed training with the LRP. It was hypothesised that the speed training would shorten the pre-motor processing and result in earlier onsets of the S-LRPs in the speed group than in the memory group, whereas the LRP-R was not expected to differ between the two groups.

2. Explore the effects of the two training procedures on face recognition (using the N250r) and on the activation of semantic representations (using the N400). Four unequivocal patterns that combine the effects of training on amplitudes and latencies of the two ERP components (compare Table 7) have been derived from findings reported by Herzmann et al. (2010). These patterns serve here as explorative hypotheses.

3. Explore the effects of the training procedures on pictorial and structural encoding (via P100 and N170, respectively). It was hypothesised that memory training, if effective, should result in larger amplitudes of the P300 than speed training, whereas the speed training should not influence these amplitudes.

2 *Method of Study 2*

2.1 Participants

Thirty seven trainees from Study 1 participated again in this study. The two persons who refused to participate in this re-training and the person who had dropped out during Study 1 were replaced by their counterparts from the last training's matched control group. During training one participant dropped out of the speed group. All participants gave informed consent to participate in the study for which they received payment of 80 €. According to the Edinburgh Handedness Inventory (Oldfield, 1971), 4 participants were left-handed, 33 right-handed, and 2 ambidextrous. All participants reported normal or corrected-to-normal visual acuity. Ten of the twenty participants in the memory training group were women as were nine of nineteen participants in the speed training group.

To exhaust the information collected during the post-test, participants with poor behavioural performance were excluded only from single tasks. Two participants from the memory group and four from the speed group were excluded from the analysis on the matching task. On the priming task, one participant from the memory training group was excluded.

2.2 Re-Training

Eight months after the beginning of training in Study 1, the same training procedures, but of reduced duration, were administered. This re-training included the first 10 sessions of each training procedure. In the memory training, the retrieval of learned stimuli from the session before is tested the following day, so that the tenth session was only completed a day later, on the eleventh day. To ensure compliance with instructions, participants emailed their log files after the first 5 sessions and at the end of training.

The face memory task *Acquisition curve*, taken from the test battery (for details see Herzmann et al., 2008), was included at the end of the last training session. This task had been administered to these participants on three previous test occasions in Study 1 (compare Figure 1). The faces learned here served as familiar stimuli in the priming task of the post-test.

2.3 Post-Test

After the re-training, participants completed a post-test consisting of two tasks, a matching task followed by a priming task, while the electroencephalogram (EEG) was recorded. Participants accomplished the post-test with a varying time delays after their last re-training session ranging from one to nine days ($M = 3.21$ days). This interval did not differ between the training groups, $F < 1$.

2.3.1 Stimuli and Apparatus

A total of 450 faces and 170 houses was used in the post-test. All stimuli were black-and-white photographs. For the matching task, stimuli were taken from perception and speed tasks by Herzmann et al. (2008) and Hildebrandt et al. (2010). For the priming task, familiar stimuli were 30 faces taken from the task *Acquisition curve* as described above. Further 240 faces taken from Endl et al. (1998) served as unfamiliar stimuli. Portraits of familiar and unfamiliar faces were homogenised across conditions with respect to luminance and size. All faces showed neutral expressions or weak smiles without exposing teeth and had no beards or glasses. In order to exclude external features, all portraits were fitted into a vertical oval 184 by 276 pixels (7.0 by 10.2 cm; 5.7° by

8.8° of visual angle) leaving only the face up to the hairline visible (see Figure 11). The sexes were represented equally in all stimulus sets. All pictures of houses were 270 by 187 pixels (7.1 by 10.0 cm; 8.3° by 6.0° of visual angle). Stimuli were always shown in the centre of a light gray computer monitor at a viewing distance of 70 cm. For stimulus presentation and response recordings Presentation 13.0 software was used.

2.3.2 Design and Procedure

All sessions were conducted in an electrically shielded, sound-attenuated cabin. At the beginning of each task, participants received written task instructions followed by a practice block with feedback given immediately after each answer. No feedback was given during the following test blocks. Both speed and accuracy were emphasised. Both tasks were two-choice reaction time tasks with a constant order of stimuli. The assignment of buttons to answers was counter balanced. Matched and unmatched trials were equally probable as were primed and unprimed trials. In a trial, both faces were always of the same sex. Short, self-paced breaks were allowed after each block.

Matching Task. This task was a delayed identity matching with 8 blocks and 50 trials each. All trials (Figure 11, Panel A) started with a fixation cross shown for 200 ms, followed by a prime stimulus, presented for 500 ms, and replaced by a mask with a fixation point, shown for 1.3 sec. Then, the target was presented for 1.3 sec. The interval between target onsets was 5 sec. The task started with a practice block, which ended after 5 consecutive correct responses or after a maximum of 15 trials. In the first four experimental blocks, participants matched faces and in the last four blocks houses. The assignment of hand to matching condition changed after Block 2 and Block 6 to meet the requirements for the analysis of the LRP. Thus, each participant had an equal number of trials for each hand assignment and stimulus domain. Each change of hand assignment began with a further practice block.

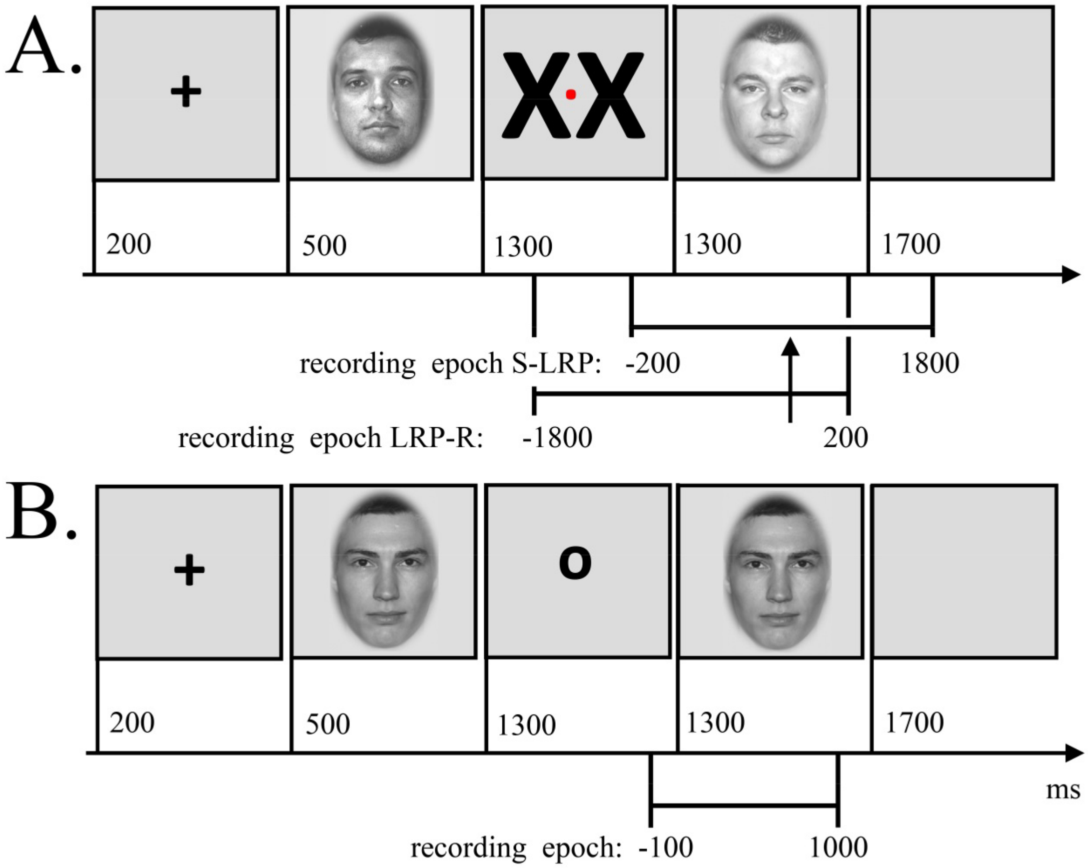

Figure 11. Trial sequences of the matching (Panel A) and priming (Panel B) task. Panel A shows a non-matching trial and Panel B shows a primed trial with a target face that had been learned.

Priming Task. Recognition of learned faces was tested in the repetition priming paradigm. Trials (Figure 11, Panel B) started with a fixation cross shown for 200 ms, followed by a prime face, presented for 500 ms, and replaced by a fixation circle, shown for 1.3 sec. Then, the target face was presented for 1.3 sec. The interval between target onsets was 5 sec. The prime face was either the same stimulus as the target face (primed condition) or an unrelated one (unprimed condition), which was either an unfamiliar prime for a familiar target or a familiar prime for an unfamiliar target. The instruction was to ignore the prime stimulus and indicate by key press whether the target face was familiar or not. The assignment of the left or the right key for familiar and unfamiliar targets was counter balanced across the two training groups. The task started with 4 practice trials. Subsequently, 8 experimental blocks followed with 40 trials each. In order to acquire enough trials for ERP analysis, familiar target items were shown repeatedly intermixed with novel, unfamiliar distracters.

2.4 Performance Measurement

Re-training courses over the 10 sessions were analysed to determine whether there was behavioural evidence of training-induced changes. For the memory training, marginal increases were expected in the product of hits and training level[10]. For the speed training, reductions of reaction times were expected. For the courses of the re-training and for both post-test tasks, the behavioural data were analysed in the same manner as in Study 1.

2.5 Event-Related Potential Recording

The EEG was recorded with sintered Ag/AgCl scalp electrodes mounted in a cap (Easy-Cap™) at the following positions: Fz, Cz, Pz, Iz, Fp1, Fp2, F3, F4, F7, F8, FT9, FT10, C3, C4, T7, T8, TP9, TP10, P3, P4, P7, P8, P9, P10, PO9, PO10, O1, O2, F9’ und F10’ (Pivik et al., 1993). The F9’ and F10’ electrodes were placed 2 cm anterior to the F9 and F10 electrodes at the outer canthi of the left and the right eye, respectively. TP9 and TP10 relate to inferior temporal locations above the left and the right mastoids. The recording was referenced unipolarly against left mastoid (TP9) and the AFz served as

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[10] Changes in reaction times cannot be compared over time for the memory training because better performance resulted in a higher level, thus, increasing demand and also influencing the reaction times.

ground. Impedances were kept below 5 kΩ. The horizontal electrooculogram was recorded from the electrodes F9' and F10'. The vertical electrooculogram was recorded from Fp1, Fp2, and from two additional electrodes placed beneath the left and the right eye, respectively. The EEG was digitised at a sampling rate of 500 Hz with a band-pass of 0.016 to 70 Hz and a notch filter at 50 Hz.

2.6 Preparation of Electrophysiological Measures/Data Analysis

Off-line, blink-contaminated trials were corrected using the method implemented in BESA 5.1. Next, the EEG was re-referenced to average reference and digitally filtered with a high cut-off set to 30 Hz. The continuous signal was cut in epochs around the target onsets (compare Figure 11). In the matching task, different epochs had to be cut for the analyses of the two LRP components: the epochs began 200 ms prior to the target onsets for the S-LRP and 1800 ms prior to the reaction for the LRP-R. All LRP epochs lasted a total of 2000 ms. The epochs of the priming task began 100 ms prior to target onsets and lasted a total of 1100 ms. All segments with non-ocular artefacts (0.9%), responses faster than 201 ms (1.7%), or incorrect responses (4.0%) were discarded. For S-LRP and for the priming task, segments were baseline-corrected with the epoch prior to target onset. The LRP-R waveform was referred to a baseline of 200 ms before the onset of the slowest individual response in this condition (compare Abdel Rahman, Sommer, & Schweinberger, 2002; Martens, Leuthold, & Schweinberger, 2010). The segments were averaged separately for each channel and experimental condition. The experimental effects for the LRP were analysed as difference waves between the contralateral and ipsilateral site of the response hand at the electrode sites C3 and C4. The difference waves were averaged across left- and right-hand responses. The onset of each LRP was established as the first time point when the signal reached 50% of its peak amplitude using the jackknife-based procedure by Miller, Patterson, and Ulrich (1998).

In the priming task, the ERP components N250r and N400 were quantified as mean amplitude relative to a 100-ms baseline preceding stimulus onset. The effects were analysed in 6 adjacent 50-ms segments between 200 and 500 ms. Further, individually scaled topographies of adjacent segments were analysed to study the effects of the two training procedures on the repetition effects. If the scalp topography of a component differs between the groups, this would indicate that at least partially different neural generators were active. Topographies were scaled to the same overall amplitude with each participant’s difference waveform divided by the individual ERPs average distance from the mean (Haig, Gordon, & Hook, 1997). This procedure was repeated separately for each condition.

The components P100 and N170 were analysed at the electrode sites they were most prominent at because they are well delineated in time and topography. The component P300 is less circumscribed in time, thus, besides analysing the effects at the site it was most pronounced at, additionally, mean activity measures were analysed.

3 Results of Study 2

Huynh-Feldt corrected analyses of variance with repeated measures were calculated. The within-subject factors were matching (matched, unmatched) and stimulus domain (faces, houses) in the matching task and priming (primed, unprimed) and familiarity (familiar, unfamiliar) in the priming task. In both tasks, group (memory, speed) was the between-subjects factor and for all EEG analyses the within-subject factor electrode (32) was included. Referencing to a common average sets the mean activity over all electrodes to zero. Effects in such ERP-analyses are only meaningful if there is an interaction with electrode. Hence, only such results will be reported, and for brevity the factor electrode will not be mentioned. The significant post-hoc analyses were Bonferroni corrected and are reported with uncorrected degrees of freedom and corrected *p*-values. The focus of this study was on differences between the two training groups, therefore, main effects of group or interactions with group will be regarded in detail.

In the following sections, the effectiveness of the re-training procedures in the courses of the daily training sessions will be addressed first. Next, the results of the post-test will be reported for the matching and the priming task, respectively.

3.1 Courses of the Re-Training

The courses of the two re-training procedures (sessions 1 to 10) are depicted in Figure 12. A regression analysis on the courses of the memory training revealed no increase in performance, $t < 1$[11]. The significant standardised regression coefficients for the odd-man-out of $b = -.700$ ($t(8) = -2{,}78$, $p < .05$, $f = .982$) and for the 1-back task of b

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[11] Comparisons of the reaction times of the first 10 sessions of the memory training from Study 1 (M = 1912 ms, SD = 50 ms) to the 10 sessions of re-training in Study 2 (M = 1721 ms, SD = 39 ms) revealed that throughout the reaction times of the re-training were slower, Fs ≥ 5.10, ps < .05 on 8 days and on 2 days Fs < 3.9, ps > .05.

= -.829 ($t(8) = -4.20$, $p < .01$, $f = 1.485$) indicated reaction times were reduced over the course of the re-training.

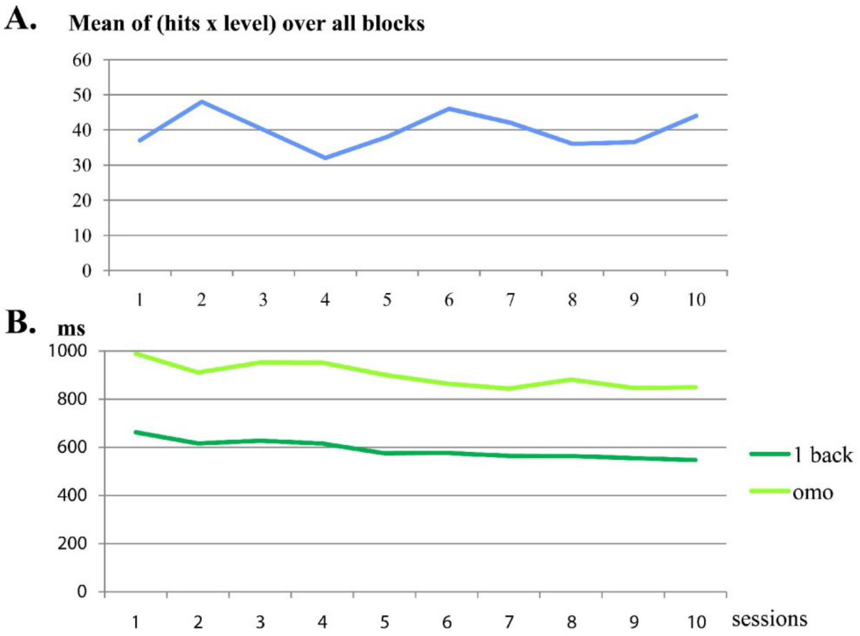

Figure 12. Trainees' performance over the courses of the re-training for face memory (Panel A) and for facial speed (Panel B). 1 back: 1-back task; omo: odd-man-out task.

Mean reaction times at the beginning of the re-training in Study 2 *(M*s = 1038 ms, 695ms for the odd-man-out and the 1-back task, respectively) were shorter than at the beginning of training in Study 1 *(M*s = 1383 ms, 1024 ms for the odd-man-out and the 1-back task, respectively), *F*s(1, 19) = 27.088, 48.362, *p*s < .001, *f*s = .611, 1.739, for the odd-man-out task and the 1-back task, respectively. Mean reaction times at the end of the re-training in Study 2 did not differ from mean reaction times at the end of training in Study 1, both trained tasks *F*s < *1.*

3.2 Results of the Matching Task in the Post-Test

3.2.1 Behavioural Data

Table 8 summarises the behavioural data for both training groups, for each stimulus domain, and matching condition. There was a trend for lower accuracies in the speed group, $F(1, 31) = 3.51$, $p = .071$, $f = .128$. There were no other main effects or interactions in the accuracies, *F*s < 2.5, *p*s > .129.

Table 8. Means and Standard Deviations of Behavioural Data for the Matching Task

	M			*SD*		
	Memory	Speed	All	Memory	Speed	All
Accuracies						
Face-matc	.947	.937	.942	.047	.061	.053
Hous-matc	.957	.929	.944	.036	.045	.042
Face-unma	.944	.926	.936	.041	.035	.039
Hous-unma	.958	.927	.944	.033	.046	.041
Reaction times						
Face-matc	656	639	648	65	83	73
Hous-matc	638	641	640	62	74	66
Face-unma	698	663	682	60	69	66
Hous-unma	678	656	668	69	81	74

Note. Memory = memory trained group, Speed = speed trained group, Face-matc = faces matched condition, Hous-matc = houses matched condition, Face-unma = faces unmatched condition, Hous-matc = houses unmatched condition.

In the reaction times[12], there was a main effect of matching, $F(1, 31) = 13.53$, $p < .001$, $f = .337$, that confirmed shorter reaction times for matched than for unmatched stimuli. There were no other main effects or interactions in reaction times, *F*s < 1.7, *p*s > .197.

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[12] For better comparison with Study 1, the reaction times were winsorized, inverted and analysed. The results were the same.

In sum, there were no increases of performance for the memory training procedure over the courses of the re-training. Whereas the courses of the speed training displayed significant training effects on both trained tasks.

3.2.2 ERP Data

Figure 13 shows the S-LRP and the LRP-R for both stimulus domains of the matching task. The LRPs are of negative-going polarity as to be expected for hand responses. The onsets of the S-LRP were virtually identical for both stimulus domains, *F*s < 1. The groups did not differ in the S-LRP onsets, *F* < 1, nor were there any other significant effects in the S-LRP onsets, *F*s < 2.5, *p*s > .125.

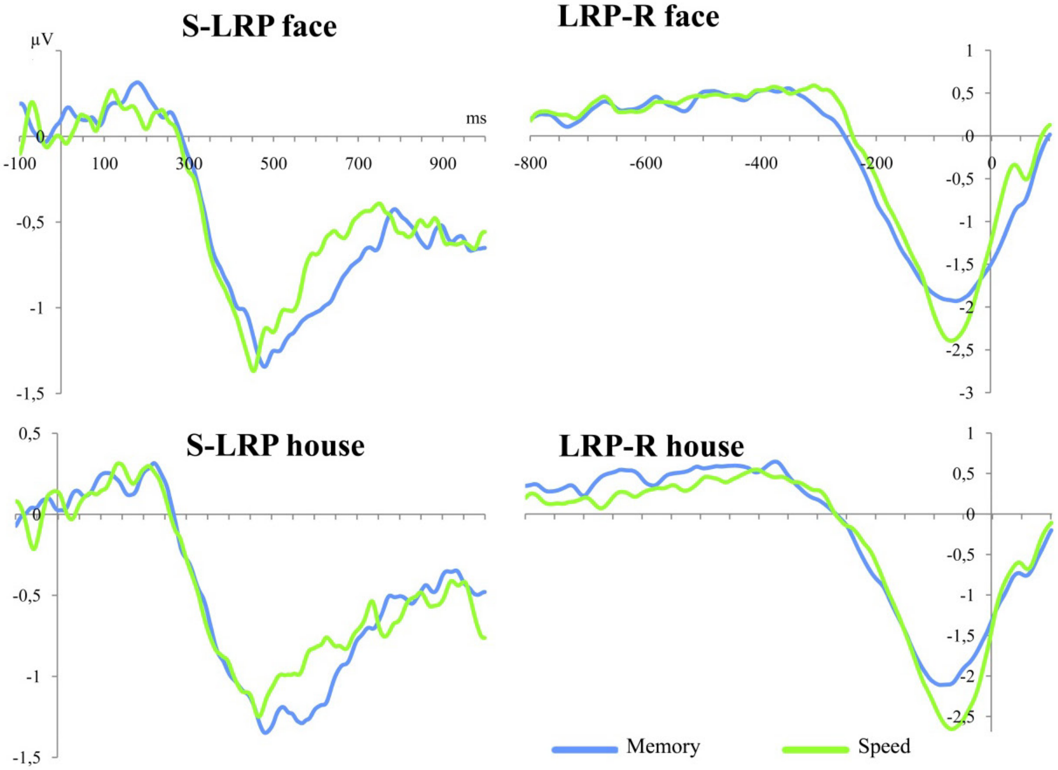

Figure 13. Matching task: grand mean lateralized readiness potential waveforms for the two training groups and stimulus domains, faces (upper panels) and houses (lower panels). The left and right panels show the stimulus- and response-synchronised waveforms (S-LRP and LRP-R), respectively.

Apart from the amplitude differences in the LRP-R, the onsets of the speed group were slightly later than those of the memory group. However, analyses revealed that the groups did not differ in the LRP-R onsets of the two stimulus domains, *F*s < 2.2, *p*s > .153. There was a main effect of matching, $F(1, 31) = 5.87$, $p < .05$, $f = .168$, such that intervals for matched stimuli were shorter than for unmatched stimuli. This finding paralleled the shorter reaction times for matched compared to unmatched trials, thus showing correspondence of behavioural and LRP data. There were no other main effects or interactions in the onsets of the LRP-R, *F*s < 2.1, *p*s > .164.

3.2.3 Summary of Results of the Matching Task

In the behavioural data, the groups did not differ in reaction times. Accordingly, the onsets of the LRPs did not differ between the two groups.

3.3 Results of the Priming Task in the Post-Test

3.3.1 Behavioural Data

Table 9 summarises the accuracy data and Figure 14 depicts the reaction times.

Table 9. Means and Standard Deviations of the Accuracies in the Priming Task

	M			*SD*		
	Memory	Speed	All	Memory	Speed	All
Prim-fami	0.969	0.961	0.965	0.043	0.044	0.043
Prim-unfa	0.974	0.973	0.973	0.031	0.031	0.031
Unpr-fami	0.967	0.956	0.961	0.041	0.034	0.038
Unpr-unfa	0.978	0.983	0.980	0.027	0.017	0.022

Note. Memory = memory trained group, Speed = speed trained group, Prim-fami = primed familiar condition, Prim-unfa = primed unfamiliar condition, Unpr-fami = unprimed familiar condition, Unpr-unfa = unprimed unfamiliar condition.

In accuracies of the priming task, there was a main effect of familiarity, $F(1, 36) = 4.19$, $p = .048$, $f = .341$, indicating that unfamiliar faces were judged more accurately. There were no other main effects or interactions, *F*s < 2.3, *p*s > .141.

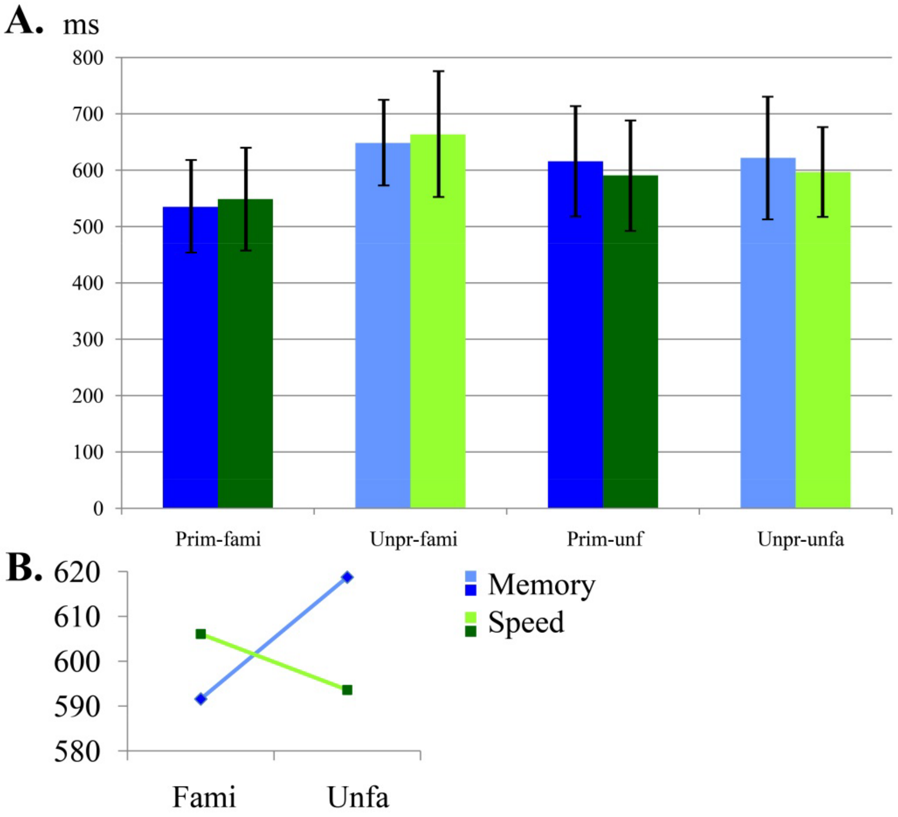

Figure 14. Reaction times of the priming task[13]*. Means across the groups and standard deviations (error bars) are presented (Panel A); Prim-fami = primed familiar condition, Unpr-fami = unprimed familiar condition, Prim-unfa = primed unfamiliar condition, Unpr-unfa = unprimed unfamiliar condition. The trend of an interaction of group with familiarity is presented in Panel B; fami = familiar condition, unfa = unfamiliar condition.*

In the reaction times[14], there was a main effect of priming, $F(1, 36) = 80.18$, $p < .001$, $f = 1.492$, with shorter reaction times for primed than for unprimed stimuli. There was also an interaction of priming with familiarity, $F(1, 36) = 103.57$, $p < .001$, $f = 1.696$. Priming influenced the familiar condition but not the unfamiliar one, $F(1, 36) = 142.59$, *p*

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[13] Exclusion of the outliers in reaction times did not change the results. Therefore, the data of these participants remained in the analyses.

[14] For comparison with Study 1, the reaction times were winsorized, inverted and also analysed. The results were the same except that one post-hoc test of the trend between familiarity and group was significant: In the memory group the inverted reaction times were larger (faster) for familiar faces than for unfamiliar faces, $F(1, 36) = 4.57$, $p < .05$, $f = .356$, but not in the speed group, $F < 1$.

< .001, $f = 1.990$, for the familiar condition and $F < 1$ for the unfamiliar condition. A trend for an interaction of group with familiarity, $F(1, 36) = 3.86$, $p = .057$, $f = .327$, indicated that in the memory group the reaction times for the familiar faces were shorter than for unfamiliar, whereas it was reversed in the speed group. However, post-hoc tests were not significant, Fs < 2.6, ps > .23.

3.3.2 ERP Data

Figure 15 depicts the grand means of the priming effects at selected electrodes, N250r in the left row and N400 in the right row.

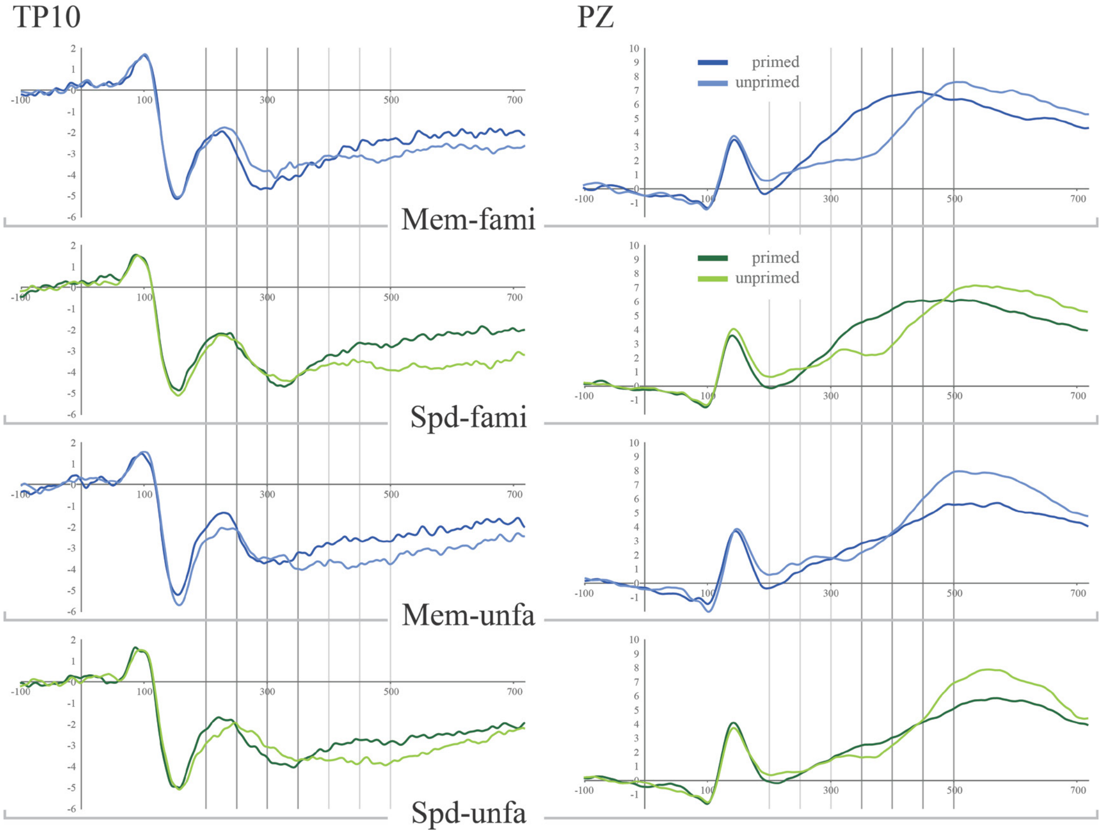

Figure 15. Priming task: waveforms of the grand means for the priming conditions (dark colours primed, light colours unprimed) depicted for familiarity and for the two training groups at the most important electrode sites: TP 10 for the N250 (left column) and the Pz for N400 (right column). Mem-fami = familiar memory group (1st row), Spd-fami = familiar speed group (2nd row), Mem-unfa = unfamiliar memory group (3rd row), Spd-unfa = unfamiliar speed group (4th row). Vertical lines mark the 50 ms segments, which were used in the ANOVAs.

The N250r component was most prominent at the TP10 electrode site as the larger negativity for primed faces as compared to unprimed faces. In the first segment (200-250 ms), this effect was reversed for unfamiliar faces in both groups as well as for familiar faces in the speed group. The N250r component was strongest in the last two segments (250-300 ms and 300-350 ms) for familiar faces in the memory group and for unfamiliar faces in the speed group. This component was almost absent for familiar faces in the speed group and for unfamiliar faces in the memory group.

The N400 component was most prominent at the Pz electrode as a larger positivity or a decreased negativity of primed compared to unprimed faces. The N400 component arose already in the segments, which fall within the N250r time window. However, it peaked within the first segment analysed for the N400, namely the 350-400 ms segment except for unfamiliar faces in the memory group. It was larger for familiar faces than for unfamiliar faces. For familiar faces, the N400 war larger in the memory group than in the speed group,while this pattern was reversed for unfamilar faces.

The analysis of peak latencies and of individually scaled topographies revealed neither differences between the groups nor any interactions with group, *F*s < 2.3. The results of the ANOVAs on the mean amplitude measures are summarised in Table 10. The ANOVAs revealed interactions between priming and familiarity as well as main effects of priming and of familiarity throughout all analysed time segments.

Table 10. Results of the Overall ANOVAs on Mean Amplitude Measures of the Priming Task Analysed in 50 ms Segments

Source	F^1	F^1	F^1	F^1	F^1	F^1
	200-250	**250-300**	**300-350**	**350-400**	**400-450**	**450-500**
Overall ANOVA						
Group (gr)	1.0	.6	.4	.5	.5	.5
Priming (pr)	**20.0*****	**9.2*****	**24.2*****	**37.5*****	**15.7*****	**13.9*****
Familiarity (fm)	**2.8***	**9.5*****	**18.2*****	**26.5*****	**29.1*****	**9.9*****
Gr * pr	.7	.5	**3.0***	.5	.6	1.3
Gr * fm	.8	.5	1.2	1.8	**2.6***	.9
Pr * fm	**3.8****	**4.9****	**17.1*****	**27.5*****	**16.3*****	**7.6*****
Gr * pr * fm	1.5	2.1(*)	2.3(*)	1.5	.5	.4

*Note. F-Values of the main effects of group, priming, familiarity, and their interactions are shown for the analysis of the respective segment. Statistical significance is indicated as * p < .05; ** p < .01; *** p < .001; (*) p < .10. Statistically significant interactions with the factor group are highlighted in grey.*

[1] *Uncorrected degrees of freedom are df(31, 1116).*

There were no main effects of group indicating that the ERPs did not generally differ between the memory and the speed group. However, there were two interactions with the group factor.

N250r. The first interaction between group and priming was significant in the 300-350 ms segment, which corresponds to the N250r time window. This interaction reflected that priming effects were larger in the memory group, $F(31, 527) = 14.73$, $p < .001$, $f = .931$, than in the speed group, $F(31, 589) = 9.41$, $p < .001$, $f = .704$. There was also a trend for a three-way interaction of group with priming and familiarity, $F(31, 1116) = 2.30$, $p = .064$, $f = .253$. Pairwise comparisons in the familiar condition revealed that the priming effects were weaker in the speed group than in the memory group (at electrode TP10: memory group -.56 µV, speed group -.22 µV), $F(31, 527) = 24.83$, $p < .001$, $f = 1.208$ for memory group, $F(31, 589) = 11.98$, $p < .001$, $f = .794$ for speed group, all other *F*s < 1.2, *p*s > .975. There were no differences in the unfamiliar condition, *F*s < 2.6, *p*s > .112.

N400. The second interaction of group with familiarity reached significance in the 400-450 ms segment, which corresponds to the N400 and indicates that familiarity affected the groups differently. Post-hoc analysis of familiarity revealed stronger familiarity effects in the memory group than in the speed group, *F*(31, 527) = 19.73, *p* < .001, *f* = 1.077 memory group and *F*(31, 589) = 11.24, *p* < .001, *f* = .769 speed group.

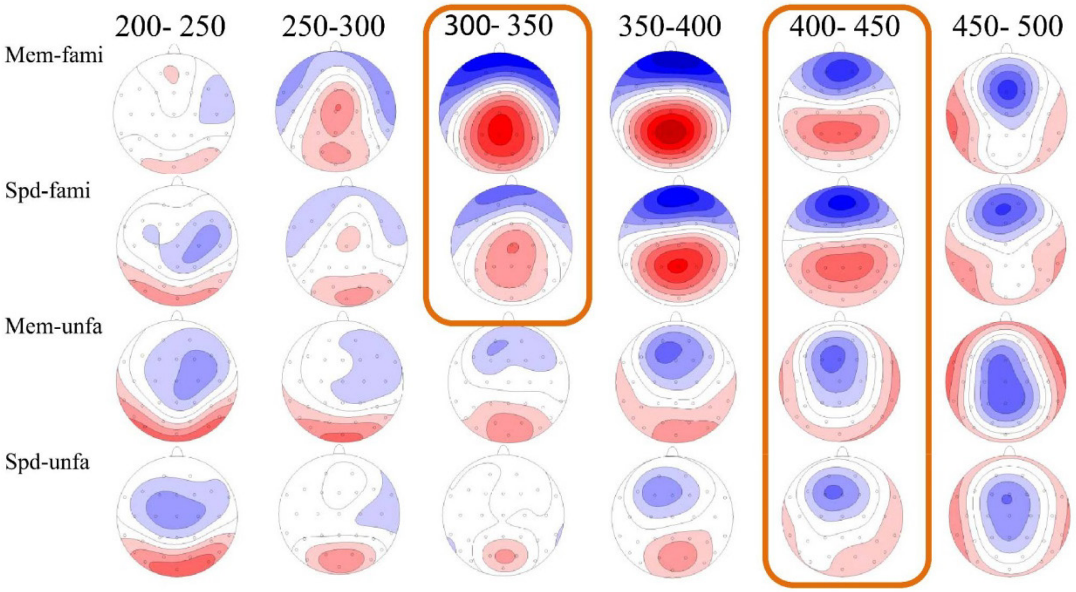

Figure 16. Topographic voltage maps of ERP differences between primed and unprimed conditions showing priming effects for the six adjacent time segments analysed for the two groups and familiarity conditions, Mem-fami = familiar memory group (1st row), Spd-fami = familiar speed group (2nd row), Mem-unfa = unfamiliar memory group (3rd row), Spd-unfa = unfamiliar speed group (4th row). Orange frames indicate segments depicting interactions with group. Spherical splines demarcate .5 µV. Negativity is shaded in blue.

P100. There were no differences between the groups in the P100 amplitudes and latencies at the Iz electrode or in the mean activity in the time window of 90-110 ms (Figure 17, Panel A), *F*s < 1.

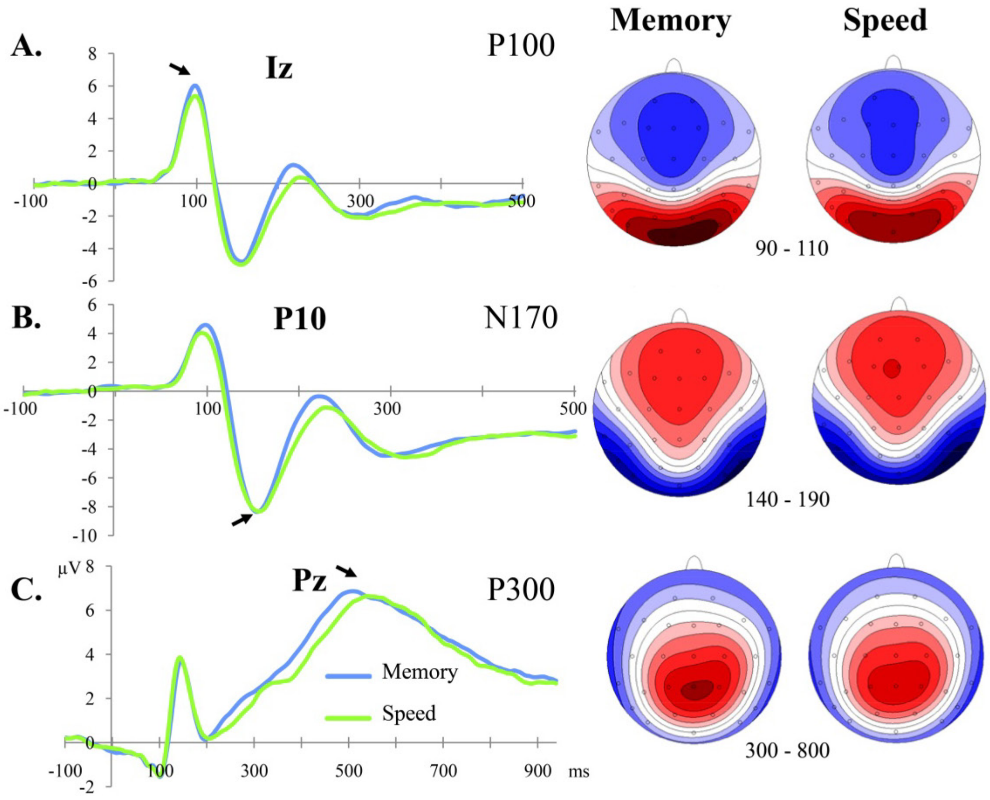

Figure 17. *Waveforms from selected electrodes and topographic voltage maps of the priming task for the components P100 (Panel A), N170 (Panel B), and P300 (Panel C) averaged over priming and familiarity conditions. Arrows indicate the peaks of the components. Spherical splines demarcate 1 µV.*

N170. There were no differences between the groups in the N170 amplitudes and latencies at the P10 electrode or in the mean activity in the time window of 140-190 ms (Figure 17, Panel B), *F*s < 1.

P300. There were no main effects of group in the peak latencies[15] and amplitudes at the electrode Pz or in the mean activity of the P300 in the time window of 300-800 ms (Figure 17, Panel C), *F*s < 1.2.

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[15] Because Figure 17 implicates that the two training groups might differ in the latencies of the P300 component but statistical analysis of the data revealed no such result, further analyses were conducted to explore this. The data was jackknifed to improve accuracy and statistical power as recommended by Kiesel and colleagues (2008). Neither the jackknifed peak latencies nor onsets differed between the groups, Fs < 1. This might be due to the relatively high variance of peak latencies in the memory group (*SD*s = 106 ms and 60 ms for memory and speed, respectively) and the lack of power to detect this effect.

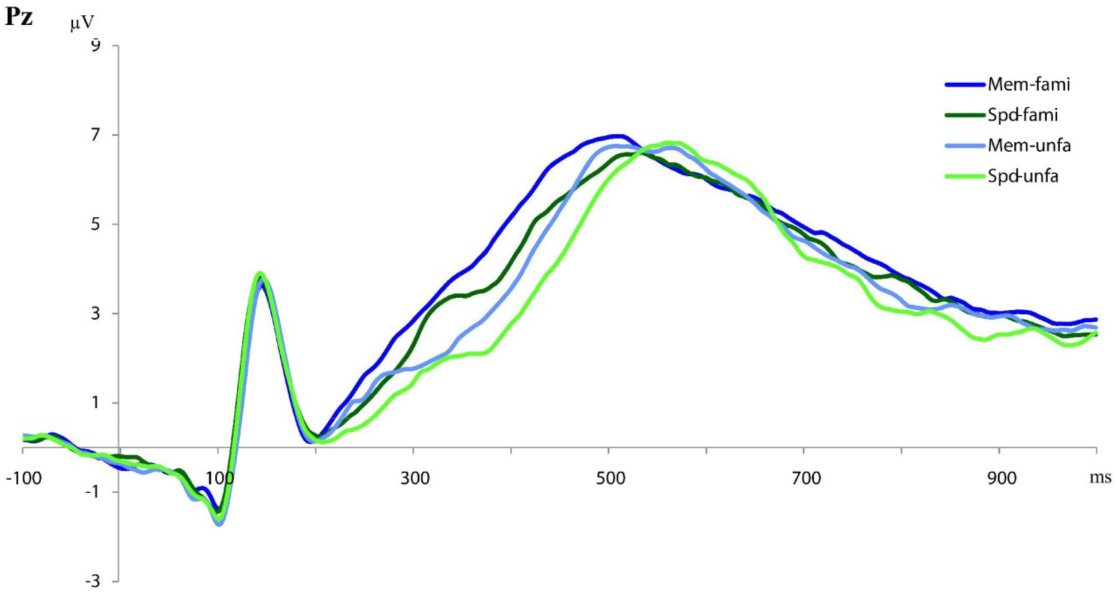

Figure 18. The P300 waveforms of the priming task for both groups and familiarity conditions (averaged over priming conditions) from the Pz electrode Mem-fami = familiar memory group, Spd-fami = familiar speed group, Mem-unfa = unfamiliar memory group, Spd-unfa = unfamiliar speed group.

As can be seen in Figure 18, group interacted with familiarity in the mean activity of the P300, *F*(31, 558) = 2.68, *p* < .05, *f* = .386. Post-hoc tests revealed that familiarity had a stronger effect on the memory group than on the speed group, *F*(31, 558) = 7.01, *p* < .001, *f* = .624 memory group and *F*(31, 589) = 2.75, *p* < .045, *f* = .380 speed group.

3.3.3 Summary of Results of the Priming Task

In the behavioural data, there was only a trend for an interaction of group with familiarity. This trend indicated that the memory group reacted faster to familiar faces, whereas the speed group reacted faster to unfamiliar faces. In the ERPs, there were two significant interactions of group with the within-subject factors. The interaction within the N250r time window indicated that priming effects were larger in the memory group than in the speed group, specifically in the familiar condition. Interactions of familiarity with group were found in the N400 and in the P300 and reflected stronger effects of familiarity in the memory group than in the speed group.

4 Discussion of Study 2

After the re-training in Study 2, the reaction time shortening within both trained speed tasks was replicated over the courses of the training. In the post-test however, the speed group did not react faster than the memory group. Because of the absence of behavioural effects, it is not possible to interpret any finding there may be in the ERPs in relation to differences in behaviour and any interpretation of the event-related data might have to be considered somewhat speculative. Nonetheless, as this is the first study that looked at ERP effects after training component abilities of face cognition, it is still interesting to consider the observed effects and to speculate on their causes.

4.1 Effects in the Courses of the Re-Training

The memory training procedure did not reveal an impact on the skill for memorising faces over the course of the re-training. In the two trained speed tasks, reaction times were significantly reduced over the course of the re-training. In fact at the end of re-training in Study 2, mean reaction times did not differ from those at the end of training in Study 1. These analyses suggest that the speed re-training was as effective as the training in Study 1.

The reaction times at the beginning of the re-training in Study 2 were faster than at the beginning of the training in Study 1, thus, indicating that the effects of training have persisted over eight months. This finding is in line with the literature. Persistence of practice-induced effects has been reported for perceptual changes one month after training (Yi, et al., 2006), for increases of performance on working memory tasks three (Klingberg, et al., 2002; Li, et al., 2008) and six months after the end of the training (Holmes, et al., 2010). A longitudinal study of fluid ability training with older adults also found that performance in re-training sessions started well below the baseline of the first training (Willis & Nesselroade, 1990). Most importantly, literature on cognitive aging research confirms that the effects of training speed of processing are persistent. Gunther, et al. (2003) report that the effects of speed of processing training persisted over a period of five months after the training. Other studies showed that 18 months after the intervention trainees performed fewer dangerous driving manoeuvres than controls or that trainees were protected from decline in health-related quality of life even 24 months post intervention (Ball, et al., 2007).

4.2 Discussion of the Behavioural Data of both Post-Test Tasks

Effects on the reaction times for the within-subject factors, repetition and familiarity, revealed that the manipulation succeeded in replicating the findings in the literature (Engst, et al., 2006; Herzmann & Sommer, 2007, 2010). As in those studies, in the present study repetition (matching and priming) reduced reaction times, namely reaction times to repeated stimuli were shorter than to unrepeated. In the reaction times of the priming task, there was a trend of an interaction of familiarity with group. This interaction indicated that the memory group reacted faster to familiar than to unfamiliar faces, whereas the pattern was reversed in the speed group. The pattern of reaction times for the speed group could indicate that these trainees were unsure about the familiarity of a learned stimulus and found it easier to judge a new face as unfamiliar. This might be due to the training, specifically, to the odd-man-out task, which emphasised the finding of differences between the presented faces. In contrast, the memory group practiced recognising the learned stimuli and might have found it easier to categorise a face as familiar than as unfamiliar as suggested by the pattern of reaction times.

The speed group reacted at the end of the re-training as fast as at the end of the training in Study 1. However, it is surprising that the reactions of the speed group were not faster than those of the memory group in the post-test. If such an improvement on the trained tasks had not been obtained with the re-training, then the null effects in the reaction times of the post-test tasks would have been uninformative. Clearly, the arising question is: Why did the two groups not differ in reaction times on the two post-test tasks? Several reasons for this lack of expected effects will be considered: First, the speed training procedure might not have been effective. This is not plausible for the reaction times at the end of the speed re-training were as short as at the end of the training in Study 1. Significant negative regressions over the courses of both trained speed tasks in Study 2 confirmed the reduction of reaction times.

Second, the memory training might have led to faster reactions in computerised tests. However, the comparison of reaction times in the courses of the memory training between the two studies revealed that trainees reacted slower during the re-training in Study 2. This finding indicates that the memory training procedure did not generally speed up computerised task solving for the memory group. Additionally, cognitive training effects tend to be specific not general (Cassavaugh & Kramer, 2009; Cavallini, Pagnin, & Vecchi, 2003; Davis, Massman, & Doody, 2001; for reviews, see Shipstead, et al., 2012; Thompson, 2005). Specifically, literature on memory enhancement through training for older participants reveals benefits for the trained tasks but very little transfer (Ball et al., 2002; Li, et al., 2008; Nyberg et al., 2003; for review, see Melby-Lervåg & Hulme, in press). Even elite memory performers who practice specific memory tasks regularly show that their superior performance is limited to the tasks and strategies practiced (see McDaniel & Bugg, 2012 for a more in-depth review). Thus, training memorising faces should not be expected to generally speed up face cognition. These considerations are also in line with the results of Study 1. Training in Study 1 was of longer training duration than in Study 2 and as latent factor analyses confirmed face memory training did not influence the ability of facial speed.

Third, the tasks administered during the post-test might not have been adequate to reveal differences between the groups due to ceiling effects both in accuracy and in reaction times. When collecting EEG data, it is important to prevent participants from making eye movements. Artefacts from eye movements decrease the signal-to-noise ratio of the averaged data because they are usually much larger than the ERP components of interest (Luck, 2005, see page 151). Both post-test tasks were for EEG requirements adapted versions of the *delayed nonmatching to sample* speed task taken from the test battery. To prevent eye movements, only one face was presented at a time rendering the task less complex. In both tasks of this post-test, the mean reaction times were significantly shorter (660 ms and 602 ms for matching and priming task, respectively) than in any of the speed tasks in Study 1 (range: 1146-1907 ms) or in the study conducted by Herzmann et al. (2008; range: 1116-2234 ms) using these same speed tasks. Additionally, both post-test tasks showed strong ceiling effects in accuracy (*M*s = .941 and .970 proportions correct for matching and priming task, respectively). Group differences in behavioural data, for example between younger and older participants, emerge more clearly on solving complex rather than easy tasks (Burke, Mackay, Worthley, & Wade, 1991; Evrard, 2002; Gollan & Brown, 2006; May, Hasher, & Kane, 1999; Schmiedek, Li, & Lindenberger, 2009; Skinner & Fernandes, 2009) or if work load is higher than if it is lower (Maddox, Balota, Coane, & Duchek, 2011; Neider et al., 2011). Other studies found group differences in psychophysical measures only for more demanding tasks (Jolles, Kleibeuker, Rombouts, & Crone, 2011; Kaufmann & Nuerk, 2008; Persson, Lustig, Nelson, & Reuter-Lorenz, 2007). The two tasks of the post-test in Study 2 were so easy that they may have allowed no space to reveal differences in behavioural measures, which could be expected from the analysis of the courses of the re-training. This seems the most plausible explanation for the absence of differences in reaction times between the two training groups.

4.3 Absent Effects of Training on ERPs

Neither the stimulus nor the reaction time locked LRPs differed between the groups. This is in line with the behavioral findings that did not show any differences in reaction times between the two training groups.

Further, there were no effects in the ERP components P100 and N170, hinting that training did not influence visual processes or that the two procedures did not differ in their influence on these processes. Both training regimes required pictorial and structural encoding. Therefore, no differential effects of training were expected for these two components.

4.4 Effects of Training on Face-Specific Components

As can be seen in Table 7, it was hypothesised that if only the speed training was effective, it would lead to larger amplitudes of the components N250r and N400 while not affecting their latencies. Whereas shorter latencies in combination with lager amplitudes for the memory group than for the speed group would indicate that only the memory training had been effective. At this general level, the two groups differed neither in amplitudes nor in latencies of these face specific components. As expected from the study by Herzmann et al. (2010), such a pattern of results implies that none of the training procedures was effective. However, at a more specific level of the within manipulated factors interactions with group were found in Study 2. Herzmann et al. (2010) did not compare groups on within-subject factors, therefore, it was not possible to predict such a pattern of results from their study. Further, they conducted a correlational study based on topographic component recognition (Brandeis, Naylor, Halliday, Callaway, & Yano, 1992), whereas the popular measure of mean amplitudes was analysed in Study 2 (Gosling & Eimer, 2011; Herzmann & Sommer, 2010; Jongen & Jonkman, 2011; Lucas, Chiao, & Paller, 2011; Tanaka & Pierce, 2009). Thus, this methodological difference might have made the patterns of results less comparable[16].

Most interestingly, post-hoc analysis at a more specific level of the within-subject factors revealed interactions with group. The first interaction of priming and group was located in the time window of the N250r and the second of familiarity with group in the N400 component time window. These two interactions will be discussed in the following sections.

4.4.1 Effects of Training on Individual Face Recognition

The interaction of priming and group in the N250r segment evinced stronger priming effects in the memory group (6 μV) than in the speed group (4 μV, see Figure

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[16] To make the two studies more comparable the N250r and N400 were also analysed with the topographic component recognition-method. In the study by Herzmann et al. (2010) both components displayed the same pattern of correlations to the component abilities. In Study 2, the results differed between the two components in amplitudes as well as in latencies. Training should have influenced both components in the same or at least similar way. Thus, no sound standing interpretation was possible.

15)[17]. As elaborated on above, the N250r has two contributions, one from structural perceptual codes and the other from representations in long-term memory (Dörr, et al., 2011). Both procedures trained perception and for both formations of structural representations were necessary. However, only the memory procedure required formation, storage, and retrieval of long-term memory representations. It might be possible to discern which training affected the N250r by comparing the sizes of the priming effects of the two training groups to those in the literature.

An effective speed training, relying primarily on pictorial and structural codes, could be expected to reduce the contribution of the representations from long-term memory to the N250r component. This could express as diminished amplitude of the N250r component in the speed group compared to the literature. On the other hand, the memory training tested the recognition of learned faces also for faces learned the previous day. Such learning requires long-term memory representations and allows for memory consolidation (Wagner, Kashyap, Diekelmann, & Born, 2007). Therefore, an effective memory training might have enhanced the contribution of the long-term memory codes to the N250r component. This should become evident as larger amplitudes for the memory group than those reported in the literature.

The amplitudes of the N250r in the memory group (6 µV) matched those reported in the literature (Bindemann, et al., 2008: 6 µV; Dörr, et al., 2011: 6 µV; Herzmann, et al., 2004: 9 µV; Herzmann & Sommer, 2007: 6 µV; Herzmann & Sommer, 2010: 8 µV; Schweinberger, Pickering, Jentzsch, et al., 2002: 7 µV), whereas the amplitudes in the

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[17] The reported size of the N250r component in µV refers to the absolute difference between the negative and positive maxima across all electrodes.

speed group (4 μV) were smaller. Therefore, it seems reasonable to assume that in the speed group the smaller amplitudes were caused by the training that reduced the contribution of the representations in long-term memory to the N250r component.

Studies on expertise trained participants on recognition of faces or face-like stimuli. They compared effects of training individuating stimuli to the effects of training their recognition at the basic level of belonging to a general category (Scott, et al., 2006, 2008; Tanaka, Curran, & Sheinberg, 2005; Tanaka & Pierce, 2009) or to the effects of other perceptual discrimination training (McGugin, Tanaka, Lebrecht, Tarr, & Gauthier, 2011). The so-called “expert” N250 component was larger for the individuated stimuli compared to the stimuli trained at the basic or perceptual discrimination level. Individuation requires perceptual codes as well as formation of memory representations. Basic or perceptual discriminations require mainly perceptual codes. Here, the memory group practiced learning individual faces during training, while the speed group performed a task similar to the perceptual discrimination training task. The smaller amplitude of the N250r component after the speed training as compared to the memory training corresponds to the difference in the “expert” N250 reported in the literature on expertise.

4.4.2 Effects of Training on Access to Semantic Information

The second interaction found was of familiarity with group in the 400-450 ms segment located within the N400 time window. This interaction indicated stronger familiarity effects in the memory group than in the speed group (see Figure 15). The N400 component is regarded as an indicator of post-perceptual processing stages connected with semantic information about persons (Eimer, 2000; Kutas & Federmeier, 2000; Paller, et al., 2000), for example the person identity nodes by Bruce and Young (1986) or the semantic information units (Burton, et al., 1990). Trainees from the memory group often reported that they used verbalisation strategies to help them memorise the faces. They invented semantic information, which they memorised together with the faces and which they later recalled to help them discriminate the targets from the distracters. The speed training, on the other hand, had almost no memory load requirement. Targets were identified mainly based on perceptual comparisons. The larger effect of familiarity in the memory group implies that these participants activated semantic information for familiar faces more strongly. Guillaume et al. (2009) found larger N400 effects for familiar faces and attributed them to deeper semantic processing compared to unfamiliar faces. Extending this argument to the present study, the larger effect of familiarity in the memory group could be also interpreted as deeper semantic processing of familiar faces in this group than in the speed group.

The comparison of effects of learning faces with and without semantic information revealed differences between these two semantic conditions in the N400 (Kaufmann, et al., 2009). Semantic information was interpreted to facilitate post-perceptual processing. Herzmann and Sommer (2010) extended these findings by further including unfamiliar faces as stimuli. They found the largest N400 for faces learned with semantic information for which all facts were remembered and concluded that these recently learned facts were more readily retrieved and more successfully activated than facts that had been learned a longer time ago. In the present study, the practice of inventing semantic information during training by the trainees from the memory group might have also been applied to learning faces for the post-test. In line with Herzmann and Sommer, such recently learned facts would have enhanced the post-perceptual processing for these recently learned stimuli and resulted in a larger N400.

The N400, though, considered an indicator of semantic information retrieval, has also been shown for unfamiliar faces (Pfütze, et al., 2002; Schweinberger, et al., 1995). Even for faces learned without semantic information a robust N400 component was found (Herzmann & Sommer, 2007). The authors interpreted their finding as indicating that participants extracted such information as gender, mood, or possibly activated own idiosyncratic memories, or invented stories. In the study reported here, only participants from the memory group reported inventing information during training. Thus, this trained practice of connecting learned faces with semantic details in the memory group might have caused the larger familiarity effects in the N400 compared to the speed group.

The finding of larger familiarity effects for the memory group than for the speed group in the mean amplitudes of the P300 parallels the familiarity effect found in the N400. Previous work has shown larger P300 amplitudes for familiar than for unfamiliar faces (Henson, et al., 2003; Joyce & Kutas, 2005). Gonzalez et al. (2011) also found larger P300 amplitudes for familiar faces and concluded that it indexed person recognition-specific processing. Paller and colleagues (2003) compared the ERPs for faces learned with one biographical fact to ERPs for new faces. They instructed participants to covertly retrieve the learned information when viewing a learned face. This instruction might resemble invention of facts that were meant to help recognise learned faces in the memory group of the present study. The absence of overt recall was regarded advantageous by Paller et al. because it eliminated interpretive difficulties due to differential behavioural responses. The authors report larger amplitudes at central and parietal sites for the learned stimuli starting 300 ms after stimulus onset. Familiarity played no role in the speed training but it was of importance in the memory training. Thus, the face memory training might have enhanced effects in components that are sensitive to face familiarity (P300 and N400) as compared to the speed training.

Though incongruous words and not faces evoked the classical N400 (Kutas & Hillyard, 1980), it is nonetheless interesting to consider the findings from this stimulus domain. Word pairs of a pronounced semantic relation elicited particularly long-lasting N400 effects (Chwilla & Kolk, 2005; Koivisto & Revonsuo, 2001). Even when such modulations of the N400 were not found, their lack was attributed to the paradigm which did not require such a semantic integration (Dell'Acqua, Pesciarelli, Jolicœur, Eimer, & Peressotti, 2007). Consistent with these findings, the memory training encouraged semantic processing of the stimuli more strongly than the speed training and, thus, also resulted in larger effects on the N400 for familiar faces.

4.5 Conclusions from Study 2

The current study expands and improves previous research on training of face cognition, but it has two limitations. First, ERPs were not measured prior to training. Hence, it cannot be ruled out that the two groups had differed in the ERP effects before the training and that the differences measured after the training and discussed above existed already beforehand. It remains for future research to replicate these findings within a pre- and post-test design while recording ERPs.

Second, only a trend for an interaction of group with familiarity appeared in the behavioural data of the post-test and paralleled the differences in effects of familiarity measured for the two training groups. Future research could use unadapted speed tasks in the post-test and try and correct eye movements. In particular, since the evoked potentials of interest manifest at central or even parietal sites such a line of action might bear clearer results than too easy tasks.

Study 2 extended the multivariate behavioural findings of Study 1 by measuring neural correlates of face cognition abilities within the same participants. The findings suggest that the training of speed of face cognition reduces contributions of structural representations from long-term memory to face identity recognition (N250r), whereas the training of face memory might enhance semantic processing of familiar faces (N400).

IV Discussion

Face cognition is a highly important ability for social interaction. Resent research suggests that there are large individual differences in face cognition, so that there might be a need for improvement by training. The present dissertation investigated enhancing face cognition by training. The general hypothesis was that it might be possible to improve face cognition by training specific components of this ability, namely face memory and speed of face cognition. These components were derived from the three factor model introduced by Wilhelm and colleagues (2010). Effects of training were assessed by means of performance data and electrophysiological recordings. In Study 1, training procedures for the two component abilities were developed, tested behaviourally, and modelled as latent ability factors within the three factor model. The facial speed training enhanced performance at the manifest as well as at the latent factor level. Persistence was evidenced at the manifest level after three months and for the trained task itself after seven months. No meaningful effects of the face memory training were found. Study 2 aimed to explore the psychophysiological underpinnings of the training-induced changes. ERP results suggested that the training of speed of face cognition reduces contributions of structural representations from long-term memory to face identity recognition, whereas the training of face memory might enhance semantic processing of familiar faces. I will briefly review the findings from these two studies, discuss them with regard to the aims of this dissertation, and develop perspectives for future research.

1 Review of Results from Study 1

In Study 1, it was hypothesised that training of the component abilities of face cognition would enhance performance. Specifically, training of face memory was hypothesised to improve the targeted component ability itself and, to a lesser extent, the highly correlated component ability of face perception. In contrast, training of speed of face cognition was hypothesised to improve only the targeted component ability itself because it is unrelated to the other two component abilities.

Study 1 was designed according to the exigencies for interventions (Hager, 2000a; Klauer, 2001; McArdle, 2009; Shipstead, et al., 2012). A 4-group quasi-experimental design was realised. Two experimental training groups, a matched as well as an unmatched control group completed the pre-test and the first post-test. After three months, all trainees and the matched controls were assessed again with the second post-test. Both trained groups experienced the same amount of attention, trained with the same equipment, under the same circumstances, and spend the same amount of time working on their tasks. Thus, motivational and novelty effects in both groups should have developed in the same way. Retest and motivational effects were controlled by contrasting the performance of each experimental group with the other experimental group's performance (Schmiedek, et al., 2010). Participants practiced at home on adaptive tasks for 29 days, approximately 15 minutes per day.

Over the courses of training, there was a trend for better performance due to the memory training and a large effect on reaction times due to the speed training. However, the post-test did not reveal any effects of training face memory. Training of facial speed led to shorter reaction times and persistence was evidenced in second post-test three months after the training. Improvement of performance was demonstrated at the latent ability level with autoregressive change models. The design applied allowed to test different aspects of validity. Convergent validity, criterion validity, and construct validity could be assumed for the speed training procedure tested here. The speed training did not influence performance on face perception but it reduced performance on face memory in the longitudinal models that partialed out the variance at pre-test. Furthermore, performance on indicator tasks for immediate and delayed memory or general cognitive ability remained unaffected. However, the speed training generalised to other speed tasks with non-face stimuli. Thus, discriminant validity for the speed training procedure could not be demonstrated for other indicators of processing speed.

The effects of training were studied at the ability level with a confirmatory factor analysis modelled in structural equations. This approach allows estimating changes within not directly measurable latent constructs and explicitly estimates measurement error. Modelling the component abilities of face cognition over time displayed three interesting results. First, the post-test was modelled as regressed on the pre-test. Therefore, all variance in the post-test that was due to variation at pre-test had been removed. For the factors face memory and facial speed the factor loadings did not vary between the two test occasions (weak invariance). In such models, the regression of the post-test onto the pre-test can be regarded as a stability coefficient over time for the variable tested (McArdle & Nesselroade, 1994). The finding of weak invariance is interesting and confirms that the component abilities face memory and facial speed as established by Wilhelm et al. (2010) and measured by the test battery developed by Herzmann and colleagues (2008) are stable over one year, the period of time that elapsed between pre- and post-test in Study 1.

Second, the constraint of equal intercepts of the factor loadings between pre- and post-test was rejected for all models. Unequal intercepts are thought to reflect a change of difficulty for single indicator tasks between the two test occasions (Byrne, et al., 1989). This change of difficulty could have been caused by retest effects and, for the speed component, by the speed training itself. However, modelling the data for the speed factor without the participants trained on speed still led to the rejection of equal intercepts. Thus, the differences in intercepts cannot be explained as an effect of training of the speed group. Possibly, retesting caused some indicators to become easier whereas others became more difficult for the participants.

Third, training of facial speed enhanced performance on speed tasks with faces and objects to the same extent and to a lesser extent on a mental speed task. Therefore, it is assumed that the training routine for facial speed investigated here influences a general speed for perception and recognition of complex stimuli (Hildebrandt, et al., 2012).

With regard of the pattern of unintended transfer to non-face stimuli for the facial speed training and the lack of training gains for the face memory training it was not possible to demonstrate efficacy of face cognition training. Of course, it is not possible to rule out that face memory can be trained even though these findings make a strong case against such training efforts. Indeed, the presented results cast doubt on the possibility of face memory training programs and on their utility as methods of specifically enhancing face cognition skill. Nevertheless, the finding that home-based, self-administered computerised training of facial speed significantly improved speed for perception and recognition of complex stimuli and also enhanced mental speed has important implications. Speed of processing is an influential cognitive ability for independent everyday functioning of elderly persons (e.g., Edwards, et al., 2009). Therefore, such an easy to administer and low-cost program is well suited to make training benefits more widely accessible to the general public.

2 Review of Results from Study 2

Results from Study 1 are based on behavioural measures only. In Study 2, event-related potentials served as markers for the chronometric properties of the functional processes underlying the training-induced changes investigated here. It was intended to localise effects of the speed training with a component differentiating between the stages of pre-motor and motor preparation. Face memory-specific components were examined to find out more about the behavioural trend found in the courses of the face memory training in Study 1. The same trainees participated in a 10-session re-training. The next paragraphs adumbrate the findings from Study 2 in the courses of the daily training sessions, the lack of behavioural findings in the post-test, and the psychophysiological findings.

Study 2 confirmed and extended the findings from Study 1 for the speed training procedure. In the courses of the speed training procedure, there were three important and impressive results. First and foremost, performance at the end of Study 2 did not differ from performance at the end of Study 1. In Study 1, these training-induced changes at manifest level have been shown to exert the intended influence at the level of the component ability. Thus, this result is taken to indicate that the re-training was effective. Second, in Study 2 approximately one-third of the training dose was sufficient to bring performance on both trained tasks to the same level as compared with findings from Study 1. This result augurs that for a re-training a shorter duration is effectual compared to the initial training. Third, the evidence for persistence of training-induced changes is very interesting. Specifically, performance at the beginning of the speed re-training was faster than at the beginning of the first training. The time lag between the end of training in Study 1 and the beginning of Study 2 was seven months. This finding shows that the task-specific training effects persisted over a long period of time. There were no effects of training in the courses of the memory training in Study 2.

The training effects were further assessed with a post-test. The two training groups did not differ in their behavioural performance at post-test. It is assumed that this lack of differences was neither due to shortening of reaction times by the memory training nor to ineffectiveness of the speed training. A shortening of reaction times in the memory re-training would constitute an arbitrary far transfer effect (e.g., Melby-Lervåg & Hulme, in press), for there were no such effects after the much longer training in Study 1 nor were there any improvements in reaction times in the courses of the memory re-training. As discussed above, the speed re-training is assumed to have been effective. The absence of behavioural differences in the post-test is attributed to the administration of too easy tasks. If a task is relatively easy, there is no room for any substantial interindividual variability (Herzmann, et al., 2008). The finding that an easy task may obscure group differences corresponds to the literature (e.g., Gollan & Brown, 2006) and is in itself interesting.

Effects of training emerged at the psychophysiological level, namely in components associated with recognition of individual faces (N250r) and with access to person-related semantic information (N400). The N250r has been shown to receive contributions from structural perceptual codes and from long-term memory representations (Dörr, et al., 2011). The speed training procedure reduced the contributions of representations from long-term memory to the processes underlying the recognition of individual faces indexed by a reduction of amplitude of the N250r component. The speed training procedure required fast comparisons of face images. For this purpose, storage of representations in long-term memory or their activation was not required.

The memory training improved access to person-related semantic information indexed by the N400 component. This training regime required formation of face representations and their storage in long-term memory. Specifically, the difficult distinction between target and distracter might have caused participants to try harder to recollect semantic information generated during the study block. Indeed, participants in the memory group reported that they memorised the faces by inventing semantic information about them (compare Herzmann, et al., 2010; Herzmann & Sommer, 2007; Tacikowski, Jednorog, Marchewka, & Nowicka, 2011).

To summarise, findings from the training courses of Study 2 demonstrate that the effects of facial speed training are long-lasting. Furthermore, psychophysiological results suggest that both procedures exert influence at this level, namely that facial speed training reduces the memory contributions to individual face recognition and that memory training enhances the access to semantic information about faces.

3 Perspectives

Future research should enhance our understanding of training face cognition by extending the findings presented here. The following paragraphs suggest further research for facial speed and for face memory. Further, propositions for investigating face perception training are made.

The effects of the speed training were strong and persistent. However, some issues could not be resolved with the present studies and should be tested more directly in future research, for example, it was impossible to determine what factor or what combination of factors of this training procedure was effective. Was it one of the tasks or the combination of both? Was the adaptation of difficulty levels during training or the game-like character of the tasks effective? Future research will have to determine if a training of perception speed on simple stimuli generalises to perception speed for complex stimuli like faces and objects. Further, it remains unanswered whether the effect of training speed of face cognition extends to measures of daily life or professional success, whether there are individual differences that moderate training and transfer, and what are the upper limits for improvement.

No support for enhancement of face memory through training was found in the data presented here. A training of a longer duration than 29 sessions might be needed to allow for improvements as suggested by the marginal increase in performance found in Study 1. The causality would be clearer if the adaptation was achieved by changes of the memory set rather than by increases of perceptual demand. This study was conceptually founded on face cognition theories, realised according to the state-of-the-art recommendations for cognitive intervention programmes, and effects were studied at the factorial construct level. However, no substantial enhancement of face memory performance was found. Therefore, the usefulness and cost-effectiveness of a training regime for face memory as compared to training the other two components of face cognition appears to be limited.

In application to both procedures, larger training groups might allow modelling the data in latent change models and thus reveal more about the influence of training. However, training larger groups is more costly. To ensure that the differences in event-related potentials did not already exist before the training a baseline should be established prior to the intervention (see Hager, 2000b; Klauer, 2001).

Though the ability of face cognition has been shown to be strongly heritable (M. Grueter et al., 2007; Wilmer et al., 2010; Zhu et al., 2010), training of face perception was successful in a case study with a participant with a hereditary impairment of face cognition (DeGutis, et al., 2007), as well as in a study of training the verification of identity (Chiller-Glaus, et al., 2007). It would be very interesting to explore the training of face perception further. For example, training could build on the parsimonious procedure introduced by DeGutis and colleagues (2007), which trains to discriminate faces by their spatial configuration. Future studies should extend the findings to healthy participants, include active control groups, assess the effects with multivariate test batteries (e.g., Herzmann, et al., 2008), and train groups large enough for structural equation modelling. Thus, effectiveness of training could be assessed at the latent ability level and the extent of transfer to the other component abilities of face cognition could be evaluated. Additionally, face perception-specific electrophysiological components could shed more light onto underpinnings influenced by this training.

CONCLUSION

The present results provide empirical support for the plasticity of speed of face cognition. Changes induced by facial speed training were shown at the manifest and at the latent ability level. The manifest effects persisted over three months and at the level of the specific training task over seven months. Because these effects generalised to speed tasks with non-face stimuli, this training was reassessed as influencing the ability of speed for the perception and recognition of complex stimuli. The amount of stimuli used, the duration of the training regime, and the psychometric profundity go far beyond other training studies for face cognition. The versatility of the effects of the speed training is a major strength since with an aging population interventions aimed at prolonging independence will be of increasing importance. For the component ability of face memory, only a trend for improved performance could be shown in the courses of the training in Study 1. In Study 2, event-related potentials indicated an improved access to person-related semantic information. However, in the absence of behavioural changes, this result cannot be regarded as an improvement of the component ability itself. The findings of a trend for task specific performance improvement in face memory and of a generalisation of the facial speed training in the present work provide insufficient evidence of the efficacy of training face cognition. Studies with no or with little effect tend to remain unpublished thus leading to an overestimation of significant training effects in the literature, the "file drawer effect" (Ranganath, et al., 2011). Therefore, it is important to publish such results. To my knowledge, this was the first investigation which combined multivariate behavioural measures with psychophysiological indicators to study the effects of training on the component abilities of face cognition. The transfer of the effects of the speed of face cognition training to everyday functioning remains uncertain as yet. Nonetheless, the current work has shed light on the plasticity of face cognition.

REFERENCES

Abdel Rahman, R. (2011). Facing Good and Evil: Early Brain Signatures of Affective Biographical Knowledge in Face Recognition. *Emotion, 11*(6), 1397-1405.

Abdel Rahman, R., Sommer, W., & Schweinberger, S. (2002). Brain-potential evidence for the time course of access to biographical facts and names of familiar persons. *Journal of Experimental Psychology-Learning Memory and Cognition, 28*(2), 366-373.

Avidan, G., Thomas, C., & Behrmann, M. (2008). An integrative approach towards understanding the psychological and neural basis of congenital prosopagnosia. In M. Jenkin & L. R. Harris (Eds.), *Cortical mechanisms of vision* (pp. 241-270). New York: Cambridge University Press.

Ball, K., Berch, D. B., Helmers, K. F., Jobe, J. B., Leveck, M. D., Marsiske, M., et al. (2002). Effects of cognitive training interventions with older adults - A randomized controlled trial. *Jama-Journal of the American Medical Association, 288*(18), 2271-2281.

Ball, K., Edwards, J. D., & Ross, L. A. (2007). The impact of speed of processing training on cognitive and everyday functions. *Journals of Gerontology Series B-Psychological Sciences and Social Sciences, 62*, 19-31.

Barnett, V., & Lewis, T. (1994). *Outliers in statistical data* (3 ed.). Chichester: Wiley.

Beck, M. R., Peterson, M. S., & Angelone, B. L. (2007). The roles of encoding, retrieval, and awareness in change detection. *Memory & Cognition, 35*(4), 610-620.

Begleiter, H., Porjesz, B., & Wang, W. Y. (1995). Event-Related Brain Potentials Differentiate Priming and Recognition to Familiar and Unfamiliar Faces. *Electroencephalography and Clinical Neurophysiology, 94*(1), 41-49.

Behrmann, M., Marotta, J., Gauthier, I., Tarr, M. J., & McKeeff, T. J. (2005). Behavioral change and its neural correlates in visual agnosia after expertise training. *Journal of Cognitive Neuroscience, 17*(4), 554-568.

Belleville, S., Gilbert, B., Fontaine, F., Gagnon, L., Menard, E., & Gauthier, S. (2006). Improvement of Episodic Memory in Persons with Mild Cognitive Impairment and Healthy Older Adults: Evidence from a Cognitive Intervention Program. *Dementia and Geriatric Cognitive Disorders, 22*(5), 486-499.

Benson, P. J., & Perrett, D. I. (1993). Extracting Prototypical Facial Images from Exemplars. *Perception, 22*(3), 257-262.

Bentin, S., Allison, T., Puce, A., Perez, E., & McCarthy, G. (1996). Electrophysiological studies of face perception in humans. *Journal of Cognitive Neuroscience, 8*(6), 551-565.

Bentin, S., DeGutis, J. M., D'Esposito, M., & Robertson, L. C. (2007). Too many trees to see the forest: Performance, event-related potential, and functional magnetic resonance imaging manifestations of integrative congenital prosopagnosia. *Journal of Cognitive Neuroscience, 19*(1), 132-146.

Bentin, S., & Deouell, L. Y. (2000). Structural encoding and identification in face processing: ERP evidence for separate mechanisms. *Cognitive Neuropsychology, 17*(1-3), 35-54.

Bindemann, M., Burton, A. M., Leuthold, H., & Schweinberger, S. (2008). Brain potential correlates of face recognition: Geometric distortions and the N250r brain response to stimulus repetitions. *Psychophysiology, 45*(4), 535-544.

Bindemann, M., & Sandford, A. (2011). Me, myself, and I: Different recognition rates for three photo-IDs of the same person. *Perception, 40*(5), 625-627.

Boehm, S. G., Klostermann, E. C., & Paller, K. A. (2006). Neural correlates of perceptual contributions to nondeclarative memory for faces. *Neuroimage, 30*(3), 1021-1029.

Boehm, S. G., Sommer, W., & Lueschow, A. (2005). Correlates of implicit memory for words and faces in event-related brain potentials. *International Journal of Psychophysiology, 55*(1), 95-112.

Bollen, K. A., & Curran, P. J. (2006). *Latent curve models : a structural equation perspective*. Hoboken, N.J.: Wiley-Interscience.

Bolte, S., Hubl, D., Feineis-Matthews, S., Prvulovic, D., Dierks, T., & Poustka, F. (2006). Facial affect recognition training in autism: Can we animate the fusiform gyrus? *Behavioral Neuroscience, 120*(1), 211-216.

Bortz, J., & Döring, N. (2006). *Forschungsmethoden und Evaluation für Human- und Sozialwissenschaftler* (4 ed.). Heidelberg: Springer Medizin Verlag.

Bourne, L. E., Healy, A. F., Pauli, P., Parker, J. T., & Birbaumer, N. (2005). The influence of stimulus array on training of a speeded response. *American Journal of Psychology, 118*(3), 385-411.

Brandeis, D., Naylor, H., Halliday, R., Callaway, E., & Yano, L. (1992). Scopolamine Effects on Visual Information-Processing, Attention, and Event-Related Potential Map Latencies. *Psychophysiology, 29*(3), 315-336.

Bredart, S., Valentine, T., Calder, A. J., & Gassi, L. (1995). An Interactive Activation Model of Face Naming. *Quarterly Journal of Experimental Psychology Section A-Human Experimental Psychology, 48*(2), 466-486.

Bruce, V., & Young, A. (1986). Understanding Face Recognition. *British Journal of Psychology, 77*, 305-327.

Brunsdon, R., Coltheart, M., Nickels, L., & Joy, P. (2006). Developmental prosopagnosia: A case analysis and treatment study. *Cognitive Neuropsychology, 23*(6), 822-840.

Bruyer, R., Mejias, S., & Doublet, S. (2007). Effect of face familiarity on age decision. *Acta Psychologica, 124*(2), 159-176.

Bukach, C. M., Gauthier, I., & Tarr, M. J. (2006). Beyond faces and modularity: The power of an expertise framework. *Trends in Cognitive Sciences, 10*(4), 159-166.

Bulthoff, I., & Newell, F. N. (2004). Categorical perception of sex occurs in familiar but not unfamiliar faces. *Visual Cognition, 11*(7), 823-855.

Burke, D. M., Mackay, D. G., Worthley, J. S., & Wade, E. (1991). On the tip of the tongue – what causes word finding failures in young and older adults. *Journal of Memory and Language, 30*(5), 542-579.

Burton, A. M., Bruce, V., & Johnston, R. A. (1990). Understanding Face Recognition with An Interactive Activation Model. *British Journal of Psychology, 81*, 361-380.

Burton, A. M., Jenkins, R., Hancock, P. J. B., & White, D. (2005). Robust representations for face recognition: The power of averages. *Cognitive Psychology, 51*(3), 256-284.

Burton, A. M., Jenkins, R., & Schweinberger, S. (2011). Mental representations of familiar faces. *British Journal of Psychology, 102*, 943-958.

Byrne, B. M. (2001). Introduction: Basic Concepts *Structural Equation Modeling With Amos: Basic Concepts, Applications, and Programming* (pp. 4-8). Mahwah, NJ: Lawrence Erlbaum Associates.

Byrne, B. M., Shavelson, R. J., & Muthen, B. (1989). Testing for the Equivalence of Factor Covariance and Mean Structures — the Issue of Partial Measurement Invariance. *Psychological Bulletin, 105*(3), 456-466.

Byrne, B. M., & Stewart, S. A. (2006). The MACS approach to testing for multigroup invariance of a second-order structure: A walk through the process. *Structural Equation Modeling-A Multidisciplinary Journal, 13*(2), 287-321.

Caharel, S., Fiori, N., Bernard, C., Lalonde, R., & Rebai, M. (2006). The effects of inversion and eye displacements of familiar and unknown faces on early and late-stage ERPs. *International Journal of Psychophysiology, 62*(1), 141-151.

Caharel, S., Poiroux, S., Bernard, C., Thibaut, F., Lalonde, R., & Rebai, M. (2002). ERPs associated with familiarity and degree of familiarity during face recognition. *International Journal of Neuroscience, 112*(12), 1499-1512.

Caldara, R., Schyns, P., Mayer, E., Smith, M. L., Gosselin, F., & Rossion, B. (2005). Does prosopagnosia take the eyes out of face representations? Evidence for a defect in representing diagnostic facial information following brain damage. *Journal of Cognitive Neuroscience, 17*(10), 1652-1666.

Carmel, D., & Bentin, S. (2002). Domain specificity versus expertise: factors influencing distinct processing of faces. *Cognition, 83*(1), 1-29.

Cassavaugh, N. D., & Kramer, A. F. (2009). Transfer of computer-based training to simulated driving in older adults. *Applied Ergonomics, 40*(5), 943-952.

Cavallini, E., Pagnin, A., & Vecchi, T. (2003). Aging and everyday memory: the beneficial effect of memory training. *Archives of Gerontology and Geriatrics, 37*(3), 241-257.

Chan, D. (2000). Detection of differential item functioning on the Kirton adaption-innovation inventory using multiple-group mean and covariance structure analyses. *Multivariate Behavioral Research, 35*(2), 169-199.

Chein, J. M., & Morrison, A. B. (2010). Expanding the mind's workspace: Training and transfer effects with a complex working memory span task. *Psychonomic Bulletin & Review, 17*(2), 193-199.

Cheung, G. W., & Rensvold, R. B. (2002). Evaluating goodness-of-fit indexes for testing measurement invariance. *Structural Equation Modeling, 9*(2), 233-255.

Chiller-Glaus, S. (2009). *Testing the Limits of Face Recognition: Identification from Photographs in Travel Documents and Dynamic Aspects of Emotion Recognition.* Universität Zürich, Zürich.

Chiller-Glaus, S., Schwaninger, A., & Hofer, F. (2007, Jun-Aug). *Identity Verification from Photographs in Travel Documents: The role of Display Duration and Orientation on Performance.* Paper presented at the Proceedings of the Human Factors and Ergonomics Society 51st Annual Meeting.

Chung, S. T. L., Levi, D. M., & Li, R. W. (2006). Learning to identify contrast-defined letters in peripheral vision. *Vision Research, 46*(6-7), 1038-1047.

Churches, O., Damiano, C., Baron-Cohen, S., & Ring, H. (2012). Getting to know you: the acquisition of new face representations in autism spectrum conditions. *Neuroreport, 23*(11), 668-672.

Chwilla, D., & Kolk, H. (2005). Accessing world knowledge: Evidence from N400 and reaction time priming. *Cognitive Brain Research, 25*(3), 589-606.

Coles, M. G. H. (1989). Modern Mind-Brain Reading - Psychophysiology, Physiology, and Cognition. *Psychophysiology, 26*(3), 251-269.

Cooper, T. J., Harvey, M., Lavidor, M., & Schweinberger, S. (2007). Hemispheric asymmetries in image-specific and abstractive priming of famous faces: Evidence from reaction times and event-related brain potentials. *Neuropsychologia, 45*(13), 2910-2921.

Danthiir, V., Wilhelm, O., & Schacht, A. (2005). Decision speed in intelligence tasks: correctly an ability? *Psychology Science, 47*(2), 200-229.

Davis, R. N., Massman, P. J., & Doody, R. S. (2001). Cognitive intervention in Alzheimer disease: a randomized placebo-controlled study. *Alzheimer Disease & Associated Disorders, 15*(1), 1-9.

DeGutis, J. M., Bentin, S., Robertson, L. C., & D'Esposito, M. (2007). Functional plasticity in ventral temporal cortex following cognitive rehabilitation of a congenital prosopagnosic. *Journal of Cognitive Neuroscience, 19*(11), 1790-1802.

DeGutis, J. M., DeNicola, C., Zink, T., McGlinchey, R., & Milberg, W. (2011). Training with own-race faces can improve processing of other-race faces: Evidence from developmental prosopagnosia. *Neuropsychologia, 49*(9), 2505-2513.

Dejong, R., Wierda, M., Mulder, G., & Mulder, L. J. M. (1988). Use of partial stimulus information in response processing. *Journal of Experimental Psychology-Human Perception and Performance, 14*(4), 682-692.

Dell'Acqua, R., Pesciarelli, F., Jolicœur, P., Eimer, M., & Peressotti, F. (2007). The interdependence of spatial attention and lexical access as revealed by early asymmetries in occipito-parietal ERP activity. *Psychophysiology, 44*(3), 436-443.

Desjardins, J., & Segalowitz, S. J. (2009). Deconstruction the P1 and N170 face-effect using independent component analysis. *Psychophysiology, 46*, S24-S24.

Dörr, P., Herzmann, G., & Sommer, W. (2011). Multiple Contributions to Priming Effects for Familiar Faces: Analyses with Backward Masking and Event-Related Potentials. *British Journal of Psychology, 102*, 765-782.

Dosher, B. A., & Lu, Z. L. (2006). Level and mechanisms of perceptual learning: Learning first-order luminance and second-order texture objects. *Vision Research, 46*(12), 1996-2007.

Driscoll, D. M., Dal Monte, O., & Grafman, J. (2011). A Need for Improved Training Interventions for the Remediation of Impairments in Social Functioning following Brain Injury. *Journal of Neurotrauma, 28*(2), 319-326.

Duchaine, B. C., Dingle, K., Butterworth, E., & Nakayama, K. (2004). Normal greeble learning in a severe case of developmental prosopagnosia. *Neuron, 43*(4), 469-473.

Edwards, J. D., Delahunt, P. B., & Mahncke, H. W. (2009). Cognitive Speed of Processing Training Delays Driving Cessation. *Journals of Gerontology Series a-Biological Sciences and Medical Sciences, 64*(12), 1262-1267.

Eimer, M. (1998). The lateralized readiness potential as an on-line measure of central response activation processes. *Behavior Research Methods Instruments & Computers, 30*(1), 146-156.

Eimer, M. (2000). Event-related brain potentials distinguish processing stages involved in face perception and recognition. *Clinical Neurophysiology, 111*(4), 694-705.

Elliott, E. S., Wills, E. J., & Goldstein, A. G. (1973). The effects of discrimination training on the recognition of white and oriental faces. *Bulletin of the Psychonomic Society, 2*, 71-73.

Ellis, H. D., & Young, A. W. (1988). Training in face-processing skills for a child with acquired prosopagnosia. *Developmental Neuropsychology, 4*, 283-294.

Endl, W., Walla, P., Lindinger, G., Lalouschek, W., Barth, F. G., Deecke, L., et al. (1998). Early cortical activation indicates preparation for retrieval of memory for faces: an event-related potential study. *Neuroscience Letters, 240*(1), 58-60.

Engst, F. M., Martin-Loeches, M., & Sommer, W. (2006). Memory systems for structural and semantic knowledge of faces and buildings. *Brain Research, 1124*, 70-80.

Evrard, M. (2002). Ageing and lexical access to common and proper names in picture naming. *Brain and Language, 81*(1-3), 174-179.

Fabiani, M., Gratton, G., Chiarenza, G. A., & Donchin, E. (1990). A psychophysiological investigation of the von Restorff paradigm in children. *Journal of Psychophysiology, 4*, 15-24.

Fabiani, M., Gratton, G., & Federmeier, K. D. (2007). Event-Related Brain Potentials: Methods, Theory, and Applications. In J. T. Cacioppo, L. G. Tassinary & G. G. Berntson (Eds.), *Handbook of psychophysiology* (pp. 85-119). New York: Cambridge University Press.

Fabiani, M., Karis, D., & Donchin, E. (1986). P300 and recall in an incidental memory paradigm. *Psychophysiology, 23*(3), 298-308.

Fahle, M. (2005). Perceptual learning: specificity versus generalization. *Current Opinion in Neurobiology, 15*(2), 154-160.

Faja, S., Webb, S. J., Jones, E., Merkle, K., Kamara, D., Bavaro, J., et al. (2012). The Effects of Face Expertise Training on the Behavioral Performance and Brain Activity of Adults with High Functioning Autism Spectrum Disorders. *Journal of Autism and Developmental Disorders, 42*(2), 278-293.

Frommann, N., Streit, M., & Wölwer, W. (2003). Remediation of facial affect recognition impairments in patients with schizophrenia: a new training program. *Psychiatry Research, 117*(3), 281-284.

Gauthier, I., & Tarr, M. J. (1997). Becoming a "greeble" expert: Exploring mechanisms for face recognition. *Vision Research, 37*(12), 1673-1682.

Gauthier, I., Tarr, M. J., Anderson, A. W., Skudlarski, P., & Gore, J. C. (1999). Activation of the middle fusiform 'face area' increases with expertise in recognizing novel objects. *Nature Neuroscience, 2*(6), 568-573.

Germine, L., Duchaine, B., & Nakayama, K. (2011). Where cognitive development and aging meet: Face learning ability peaks after age 30. *Cognition, 118*(2), 201-210.

Gobbini, M. I., & Haxby, J. V. (2007). Neural systems for recognition of familiar faces. *Neuropsychologia, 45*(1), 32-41.

Golan, O., & Baron-Cohen, S. (2006). Systemizing empathy: Teaching adults with Asperger syndrome or high-functioning autism to recognize complex emotions using interactive multimedia. *Development and Psychopathology, 18*(2), 591-617.

Goldman, S. R., Mertz, D. L., & Pellegrino, J. W. (1989). Individual-Differences in Extended Practice Functions and Solution Strategies for Basic Addition Facts. *Journal of Educational Psychology, 81*(4), 481-496.

Goldstein, A. V., & Chance, J. E. (1985). Effects of training on Japanese face recognition: Reduction of the other-race effect. *Bulletin of the Psychonomic Society, 23*, 211-214.

Gollan, T. H., & Brown, A. S. (2006). From tip-of-the-tongue (TOT) data to theoretical implications in two steps: When more TOTs means better retrieval. *Journal of Experimental Psychology-General, 135*(3), 462-483.

Gonzalez, I. Q., Leon, M. A. B., Belin, P., Martinez-Quintana, Y., Garcia, L. G., & Castillo, M. S. (2011). Person identification through faces and voices: An ERP study. *Brain Research, 1407*, 13-26.

Gosling, A., & Eimer, M. (2011). An event-related brain potential study of explicit face recognition. *Neuropsychologia, 49*(9), 2736-2745.

Green, C. S., & Bavelier, D. (2008). Exercising Your Brain: A Review of Human Brain Plasticity and Training-Induced Learning. *Psychology and Aging, 23*(4), 692-701.

Grueter, M., Grueter, T., Bell, V., Horst, J., Laskowski, W., Sperling, K., et al. (2007). Hereditary prosopagnosia: the first case series. *Cortex, 43*(6), 734-749.

Grueter, T., Grueter, M., & Carbon, C.-C. (2008). Neural and genetic foundations of face recognition and prosopagnosia. *Journal of Neuropsychology, 2*(1), 79-97.

Guillaume, C., Guillery-Girard, B., Chaby, L., Lebreton, K., Hugueville, L., Eustache, F., et al. (2009). The time course of repetition effects for familiar faces and objects: An ERP study. *Brain Research, 1248*, 149-161.

Gunther, V. K., Schafer, P., Holzner, B. J., & Kemmler, G. W. (2003). Long-term improvements in cognitive performance through computer-assisted cognitive training: a pilot study in a residential home for older people. *Aging & Mental Health, 7*(3), 200-206.

Hager, W. (2000a). Wirksamkeits- und Wirksamkeitsunterschiedhypothesen, Evaluationsparadigmen, Vergleichsgruppen und Kontrolle. In W. Hager, J.-L. Patry & H. Brezing (Eds.), *Evaluation psychologischer Interventionsmaßnahmen: Standards und Kriterien: ein Handbuch* (1 ed., pp. 180-201). Bern: Verlag Hans Huber.

Hager, W. (2000b). Zur Wirksamkeit von Interventionsprogrammen: Allgemeine Kriterien der Wirksamkeit von Programmen in einzelnen Untersuchungen. In W. Hager, J.-L. Patry & H. Brezing (Eds.), *Evaluation psychologischer Interventionsmaßnahmen: Standards und Kriterien: ein Handbuch* (1 ed., pp. 153-168). Bern: Verlag Hans Huber.

Hager, W., & Hasselhorn, M. (1998). The effectiveness of the cognitive training for children from a differential perspective: A meta-evaluation. *Learning and Instruction, 8*(5), 411-438.

Hager, W., & Hasselhorn, M. (2000). Psychologische Interventionsmaßnahmen: Was sollen sie bewirken können? In W. Hager, J.-L. Patry & H. Brezing (Eds.), *Evaluation psychologischer Interventionsmaßnahmen: Standards und Kriterien: ein Handbuch* (1 ed., pp. 41-85). Bern: Verlag Hans Huber.

Haig, A. R., Gordon, E., & Hook, S. (1997). To scale or not to scale: McCarthy and Wood revisited. *Electroencephalography and Clinical Neurophysiology, 103*(2), 323-325.

Hair, J. F. J., Black, W. C., Babin, B. J., & Anderson, R. E. (2010). *Mulitvariate Data Analysis* (7 ed.). Upper Saddle River, NJ: Pearson Educational Inc.

Hancock, P. J. B., Bruce, V., & Burton, A. M. (2000). Recognition of unfamiliar faces. *Trends in Cognitive Sciences, 4*(9), 330-337.

Härting, C., Markowitsch, H. J., Neufeld, H., Calabrese, P., & Deisinger, K. (2000). *Die Wechsler-Memory-Scale-Revised: Deutschsprachige adaptation [The Wechsler Memory Scale revised: German adaptation]*. Bern, Switzerland: Huber.

Haxby, J. V., Hoffman, E. A., & Gobbini, M. I. (2000). The distributed human neural system for face perception. *Trends in Cognitive Sciences, 4*(6), 223-233.

Hayhoe, M. M., Bensinger, D. G., & Ballard, D. H. (1998). Task constraints in visual working memory. *Vision Research, 38*(1), 125-137.

Heil, M., & Rolke, B. (2004). Unattended distractor-induced priming in a visual selective attention task - N400 effects in the absence of RT effects. *Journal of Psychophysiology, 18*(4), 164-169.

Henson, R. N., Goshen-Gottstein, Y., Ganel, T., Otten, L. J., Quayle, A., & Rugg, M. D. (2003). Electrophysiological and haemodynamic correlates of face perception, recognition and priming. *Cerebral Cortex, 13*(7), 793-805.

Henson, R. N., Shallice, T., & Dolan, R. J. (2000). Neuroimaging Evidence for Dissociable Forms of Repetition Priming. *Science, 287*, 1269-1272.

Herrmann, M. J., Ehlis, A. C., Ellgring, H., & Fallgatter, A. J. (2005). Early stages (P100) of face perception in humans as measured with event-related potentials (ERPs). *Journal of Neural Transmission, 112*(8), 1073-1081.

Herzmann, G., Danthir, V., Schacht, A., Sommer, W., & Wilhelm, O. (2008). Toward a comprehensive test battery for face cognition: Assessment of the tasks. *Behavior Research Methods, 40*(3), 840-857.

Herzmann, G., Kunina, O., Sommer, W., & Wilhelm, O. (2010). Individual Differences in Face Cognition: Brain-Behavior Relationships. *Journal of Cognitive Neuroscience, 22*(3), 571-589.

Herzmann, G., Schweinberger, S., Sommer, W., & Jentzsch, I. (2004). What's special about personally familiar faces? A multimodal approach. *Psychophysiology, 41*(5), 688-701.

Herzmann, G., & Sommer, W. (2007). Memory-related ERP components for experimentally learned faces and names: Characteristics and parallel-test reliabilities. *Psychophysiology, 44*(2), 262-276.

Herzmann, G., & Sommer, W. (2010). Effects of previous experience and associated knowledge on retrieval processes of faces: An ERP investigation of newly learned faces. *Brain Research, 1356*, 54-72.

Hildebrandt, A., Schacht, A., Sommer, W., & Wilhelm, O. (2012). Measuring the speed of recognising facially expressed emotions. *Cognition & Emotion, 26*(4), 650-666.

Hildebrandt, A., Sommer, W., Herzmann, G., & Wilhelm, O. (2010). Structural Invariance and Age-Related Performance Differences in Face Cognition. *Psychology and Aging, 25*(4), 794-810.

Hildebrandt, A., Wilhelm, O., Herzmann, G., & Sommer W. (2012). Face and Object Cognition Across Adult Age. Manuscript submitted for publication.

Holmes, J., Gathercole, S. E., Place, M., Dunning, D. L., Hilton, K. A., & Elliott, J. G. (2010). Working Memory Deficits can be Overcome: Impacts of Training and Medication on Working Memory in Children with ADHD. *Applied Cognitive Psychology, 24*(6), 827-836.

Hopkins, I. M., Gower, M. W., Perez, T. A., Smith, D. S., Amthor, F. R., Wimsatt, F. C., et al. (2011). Avatar Assistant: Improving Social Skills in Students with an ASD Through a Computer-Based Intervention. *Journal of Autism and Developmental Disorders, 41*(11), 1543-1555.

Hu, L. T., & Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling: A Multidisciplinary Journal, 6*(1), 1-55.

Hurlbert, A. (2001). Trading faces. *Nature Neuroscience, 4*(1), 3-5.

Hussain, Z., Sekuler, A. B., & Bennett, P. J. (2009). Perceptual learning modifies inversion effects for faces and textures. *Vision Research, 49*(18), 2273-2284.

Huynh, H., & Feldt, L. S. (1976). Estimation of the box correction for degrees of freedom from sample data in the randomized block and split-plot designs. *Journal of Educational Statistics, 1*, 69-82.

Itier, R. J., & Taylor, M. J. (2002). Inversion and contrast polarity reversal affect both encoding and recognition processes of unfamiliar faces: A repetition study using ERPs. *Neuroimage, 15*(2), 353-372.

Itier, R. J., & Taylor, M. J. (2004). Effects of repetition learning on upright, inverted and contrast-reversed face processing using ERPs. *Neuroimage, 21*(4), 1518-1532.

Jaeggi, S. M., Buschkuehl, M., Jonides, J., & Perrig, W. J. (2008). Improving fluid intelligence with training on working memory. *Proceedings of the National Academy of Sciences of the United States of America, 105*(19), 6829-6833.

Jemel, B., Pisani, M., Calabria, M., Crommelinck, M., & Bruyer, R. (2003). Is the N170 for faces cognitively penetrable? Evidence from repetition priming of Mooney faces of familiar and unfamiliar persons. *Cognitive Brain Research, 17*(2), 431-446.

Jenkins, R., & Burton, A. M. (2011). Stable face representations. *Philosophical Transactions of the Royal Society B-Biological Sciences, 366*, 1671-1683.

Jolles, D. D., Kleibeuker, S. W., Rombouts, S., & Crone, E. A. (2011). Developmental differences in prefrontal activation during working memory maintenance and manipulation for different memory loads. *Developmental Science, 14*(4), 713-724.

Jongen, E. M. M., & Jonkman, L. M. (2011). Effects of concurrent working memory load on distractor and conflict processing in a name-face Stroop task. *Psychophysiology, 48*(1), 31-43.

Joyce, C. A., & Kutas, M. (2005). Event-related potential correlates of long-term memory for briefly presented faces. *Journal of Cognitive Neuroscience, 17*(5), 757-767.

Kaufmann, J. M., Schweinberger, S., & Burton, A. M. (2009). N250 ERP Correlates of the Acquisition of Face Representations across Different Images. *Journal of Cognitive Neuroscience, 21*(4), 625-641.

Kaufmann , L., & Nuerk, H. C. (2008). Basic number processing deficits in ADHD: a broad examination of elementary and complex number processing skills in 9-to 12-year-old children with ADHD-C. *Developmental Science, 11*(5), 692-699.

Kelly, C., Foxe, J. J., & Garavan, H. (2006). Patterns of normal human brain plasticity after practice and their implications for neurorehabilitation. *Archives of Physical Medicine and Rehabilitation, 87*(12), 20-29.

Kesslak, J. P., Nackoul, K., & Sandman, C. A. (1997). Memory training for individuals with Alzheimer's disease improves name recall. *Behavioural Neurology, 10*(4), 137-142.

Kirk, R. E. (2007). Effect magnitude: A different focus. *Journal of Statistical Planning and Inference, 137*(5), 1634-1646.

Klauer, K. J. (1995). Reevaluating Some Evaluations of A Training of Inductive Reasoning - Answers and New Results. *Zeitschrift fur Pädagogische Psychologie, 9*(1), 13-23.

Klauer, K. J. (2000). The piggyback theorem of asymmetric strategy transfer. A contribution to the theory of training and transfer. *Zeitschrift fur Entwicklungspsychologie und Padagogische Psychologie, 32*(3), 153-165.

Klauer, K. J. (2001). Einführung. In K. J. Klauer (Ed.), *Handbuch kognitives Training* (Vol. 2, pp. 3-66). Göttingen [u.a.]: Hogrefe.

Klauer, K. J. (2002). How many did really learn during training? A question which cannot yet be answered unequivocally. *Psychologie in Erziehung und Unterricht, 49*(3), 210-218.

Kliegl, R., & Philipp, D. (2006). Becoming a Demosthenes! Compensating age-related memory deficits with expert strategies. In P. C. Kyllonen, R. D. Roberts & L. Stankov (Eds.), *Extending intelligence: Enhancements and new constructs.* . Mahwah, NJ: Erlbaum.

Kliegl, R., Philipp, D., Luckner, M., & Krampe, R. T. (2001). Face memory skill acquisition. In N. Charness, D. C. Park & B. A. Sabel (Eds.), *Communication, technology and aging : Opportunities and challenges for the future* (pp. 169-186). New York: Springer.

Klingberg, T. (2010). Training and plasticity of working memory. *Trends in Cognitive Sciences, 14*(7), 317-324.

Klingberg, T., Forssberg, H., & Westerberg, H. (2002). Training of working memory in children with ADHD. *Journal of Clinical and Experimental Neuropsychology, 24*(6), 781-791.

Koivisto, M., & Revonsuo, A. (2001). Cognitive representations underlying the N400 priming effect. *Cognitive Brain Research, 12*(3), 487-490.

Krigolson, O. E., Pierce, L. J., Holroyd, C. B., & Tanaka, J. W. (2009). Learning to Become an Expert: Reinforcement Learning and the Acquisition of Perceptual Expertise. *Journal of Cognitive Neuroscience, 21*(9), 1833-1840.

Kutas, M., & Federmeier, K. D. (2000). Electrophysiology reveals semantic memory use in language comprehension. *Trends in Cognitive Sciences, 4*(12), 463-470.

Kutas, M., & Hillyard, S. A. (1980). Reading senseless sentences - brain potentials reflect semantic incongruity. *Science, 207*, 203-205.

Kutas, M., McCarthy, G., & Donchin, E. (1977). Augmenting mental chronometry - P300 as a measure of stimulus evaluation time. *Science, 197*, 792-795.

Lander, K., & Metcalfe, S. (2007). The influence of positive and negative facial expressions on face familiarity. *Memory, 15*(1), 63-69.

Lanning, K. (1991). *Consistency, scalability, and personality measurment*. New York [u.a.] Springer.

Leuthold, H., & Sommer, W. (1998). Postperceptual effects and P300 latency. *Psychophysiology, 35*(1), 34-46.

Leuthold, H., Sommer, W., & Ulrich, R. (1996). Partial advance information and response preparation: Inferences from the lateralized readiness potential. *Journal of Experimental Psychology-General, 125*, 307-323.

Li, S. C., Schmiedek, F., Huxhold, O., Rocke, C., Smith, J., & Lindenberger, U. (2008). Working Memory Plasticity in Old Age: Practice Gain, Transfer, and Maintenance. *Psychology and Aging, 23*(4), 731-742.

Lucas, H. D., Chiao, J. Y., & Paller, K. A. (2011). Why some faces won't be remembered: brain potentials illuminate successful versus unsuccessful encoding for same-race and other-race faces. *Frontiers in Human Neuroscience, 5*(20).

Luck, S. J. (2005). *An lntroduction to the Event-Related Potential Technique*. Cambridge, MA [u.a.]: MIT Press.

Maddox, G. B., Balota, D. A., Coane, J. H., & Duchek, J. M. (2011). The Role of Forgetting Rate in Producing a Benefit of Expanded Over Equal Spaced Retrieval in Young and Older Adults. *Psychology and Aging, 26*(3), 661-670.

Maichle, U. (1992). Zur Trainierbarkeit des Textverstehens und des schlußfolgernden Denkens im medizinisch-wissenschaftlichen Bereich. In H. Mandl & H. F. Friedrich (Eds.), *Lern- und Denkstrategien* (pp. 167-192). Göttingen: Hogrefe.

Malpass, R. S. (1981). Training in face recognition. In G. Davis, H. Ellis & J. Shepherd (Eds.), *Perceiving and remembering Faces* (pp. 271-285). London: Academic Press.

Malpass, R. S., Lavigueur, H., & Weldon, D. E. (1973). Verbal and visual training in face recognition. *Perception & Psychophysics, 14*, 285-292.

Mangels, J. A., Manzi, A., & Summerfield, C. (2009). The First Does the Work, But the Third Time's the Charm: The Effects of Massed Repetition on Episodic Encoding of Multimodal Face-Name Associations. *Journal of Cognitive Neuroscience, 22*(3), 457-473.

Martens, U., Leuthold, H., & Schweinberger, S. (2010). Parallel Processing in Face Perception. *Journal of Experimental Psychology-Human Perception and Performance, 36*(1), 103-121.

Masaki, H., Wild-Wall, N., Sangals, J., & Sommer, W. (2004). The functional locus of the lateralized readiness potential. *Psychophysiology, 41*, 220-230.

May, C. P., Hasher, L., & Kane, M. J. (1999). The role of interference in memory span. *Memory & Cognition, 27*(5), 759-767.

McArdle, J. J. (2009). Latent Variable Modeling of Differences and Changes with Longitudinal Data. *Annual Review of Psychology, 60*(1), 577-605.

McArdle, J. J., & Aber, M. S. (1990). Patterns of change within latent variable structural equation models. In A. Eye von (Ed.), *New statistical methods in developmental research* (pp. 151-224). New York: Academic Press.

McArdle, J. J., & Nesselroade, J. R. (1994). Using Multivariate Data to Structure Developmental Change. In S. H. Cohen & H. W. Reese (Eds.), *Life Psychology: Methodological Contributions* (pp. 223-267). Hillsdale, NJ: Erlbaum.

McArdle, J. J., & Prindle, J. J. (2008). A Latent Change Score Analysis of a Randomized Clinical Trial in Reasoning Training. *Psychology and Aging, 23*(4), 702-719.

McCarthy, G., & Donchin, E. (1983). Chronometric analysis of human information processing. In A. W. K. Gaillard & W. Ritter (Eds.), *Tutorials in event related potential research: Endogenous components.* (pp. 251-268). Amsterdam: Elsevier.

McDaniel, M. A., & Bugg, J. M. (2012). Memory training interventions: What has been forgotten? *Journal of Applied Research in Memory and Cognition, 1*(1), 45-50.

McGugin, R. W., Tanaka, J. W., Lebrecht, S., Tarr, M. J., & Gauthier, I. (2011). Race-Specific Perceptual Discrimination Improvement Following Short Individuation Training With Faces. *Cognitive Science, 35*(2), 330-347.

Meade, A. W., Johnson, E. C., & Braddy, P. W. (2008). Power and sensitivity of alternative fit indices in tests of measurement invariance. *Journal of Applied Psychology, 93*(3), 568-592.

Meeren, H. K. M., van Heijnsbergen, C. C. R. J., & de Gelder, B. (2005). Rapid perceptual integration of facial expression and emotional body language. *Proceedings of the National Academy of Sciences of the United States of America, 102*(45), 16518-16523.

Megreya, A. M., & Burton, A. M. (2006). Unfamiliar faces are not faces: Evidence from a matching task. *Memory & Cognition, 34*(4), 865-876.

Melby-Lervåg, M., & Hulme, C. (in press). Is Working Memory Training Effective? A Meta-Analytic Review. *Developmental Psychology*.

Meredith, W. (1993). Measurement Invariance, Factor-Analysis and Factorial Invariance. *Psychometrika*, *58*(4), 525-543.

Meredith, W., & Teresi, J. A. (2006). An essay on measurement and factorial invariance. *Medical Care, 44*(11), S69-S77.

Miller, J., Patterson, T., & Ulrich, R. (1998). Jackknife-based method for measuring LRP onset latency differences. *Psychophysiology, 35*(1), 99-115.

Moore, S., Sandman, C. A., McGrady, K., & Kesslak, J. P. (2001). Memory training improves cognitive ability in patients with dementia. *Neuropsychological Rehabilitation, 11*(3), 245-261.

Morrison, A. B., & Chein, J. M. (2011). Does working memory training work? The promise and challenges of enhancing cognition by training working memory. *Psychonomic Bulletin & Review, 18*(1), 46-60.

Muthén, L. K., & Muthén, B. (1998-2007). *Mplus user's guide. Fifth edition*. Los Angeles, CA: Muthén and Muthén.

Neider, M. B., Gaspar, J. G., McCarley, J. S., Crowell, J. A., Kaczmarski, H., & Kramer, A. F. (2011). Walking and Talking: Dual-Task Effects on Street Crossing Behavior in Older Adults. *Psychology and Aging, 26*(2), 260-268.

Neta, M., & Whalen, P. J. (2011). Individual differences in neural activity during a facial expression vs. identity working memory task. *Neuroimage, 56*(3), 1685-1692.

Neumann, M. F., Mohamed, T. N., & Schweinberger, S. (2011). Face and object encoding under perceptual load: ERP evidence. *Neuroimage, 54*(4), 3021-3027.

Neumann, M. F., & Schweinberger, S. (2008). N250r and N400 ERP correlates of immediate famous face repetition are independent of perceptual load. *Brain Research, 1239*, 181-190.

Nishimura, M., Maurer, D., Jeffery, L., Pellicano, E., & Rhodes, G. (2008). Fitting the child's mind to the world: adaptive norm-based coding of facial identity in 8-year-olds. *Developmental Science, 11*(4), 620-627.

Nyberg, L., Sandblom, J., Jones, S., Neely, A. S., Petersson, K. M., Ingvar, M., et al. (2003). Neural correlates of training-related memory improvement in adulthood and aging. *Proceedings of the National Academy of Sciences of the United States of America, 100*(23), 13728-13733.

Osman, A., Lou, L. G., Muller-Gethmann, H., Rinkenauer, G., Mattes, S., & Ulrich, R. (2000). Mechanisms of speed-accuracy tradeoff: evidence from covert motor processes. *Biological Psychology, 51*(2-3), 173-199.

Osman, A., & Moore, C. M. (1993). The Locus of Dual-Task Interference - Psychological Refractory Effects on Movement-Related Brain Potentials. *Journal of Experimental Psychology-Human Perception and Performance, 19*(6), 1292-1312.

Osman, A., Moore, C. M., & Ulrich, R. (1995). Bisecting RT with lateralized readiness potentials: Precue effects after LRP onset. *Acta Psychologica, 90*, 111-127.

Paller, K. A., Gonsalves, B., Grabowecky, M., Bozic, V. S., & Yamada, S. (2000). Electrophysiological correlates of recollecting faces of known and unknown individuals. *Neuroimage, 11*(2), 98-110.

Paller, K. A., Kutas, M., & Mayes, A. R. (1987). Neural Correlates of Encoding in an Incidental-Learning Paradigm. *Electroencephalography and Clinical Neurophysiology, 67*(4), 360-371.

Paller, K. A., Ranganath, C., Gonsalves, B., Labar, K. S., Parrish, T. B., Gitelman, D. R., et al. (2003). Neural correlates of person recognition. *Learning & Memory, 10*(4), 253-260.

Paulus, W. M., Homberg, V., Cunningham, K., Halliday, A. M., & Rohde, N. (1984). Color and brightness components of foveal visual evoked-potentials in man. *Electroencephalography and Clinical Neurophysiology, 58*(2), 107-119.

Persson, J., Lustig, C., Nelson, J. K., & Reuter-Lorenz, P. A. (2007). Age differences in deactivation: A link to cognitive control? *Journal of Cognitive Neuroscience, 19*(6), 1021-1032.

Pfütze, E. M., Sommer, W., & Schweinberger, S. (2002). Age-related slowing in face and name recognition: Evidence from event-related brain potentials. *Psychology and Aging, 17*(1), 140-160.

Pivik, R. T., Broughton, R. J., Coppola, R., Davidson, R. J., Fox, N., & Nuwer, M. R. (1993). Guidelines for the Recording and Quantitative-Analysis of Electroencephalographic Activity in Research Contexts. *Psychophysiology, 30*(6), 547-558.

Plendl, H., Paulus, W., Roberts, I. G., Botzel, K., Towell, A., Pitman, J. R., et al. (1993). The time course and location of cerebral evoked activity associated with the processing of color stimuli in man. *Neuroscience Letters, 150*(1), 9-12.

Polich, J. (2007). Updating p300: An integrative theory of P3a and P3b. *Clinical Neurophysiology, 118*(10), 2128-2148.

Potter, D. D., Pickles, C. D., Roberts, R. C., & Rugg, M. D. (1992). The effects of scopolamine on event-related potentials in a continuous recognition memory task. *Psychophysiology, 29*(1), 29-37.

Ramon, M., Caharel, S., & Rossion, B. (2011). The speed of recognition of personally familiar faces. *Perception, 40*(4), 437-449.

Ranganath, C., Flegal, K. E., & Kelly, L. L. (2011). Can Cognitive Training Improve Episodic Memory? *Neuron, 72*(5), 688-691.

Raven, J. C., Court, J. H., & Raven, J. (1979). *Manual for Raven's Progressive Matrices and Vocabulary Scales*. London, England: Lewis.

Rossion, B. (2002). Is sex categorization from faces really parallel to face recognition? *Visual Cognition, 9*(8), 1003-1020.

Rossion, B., Curran, T., & Gauthier, I. (2002). A defense of the subordinate-level expertise account for the N170 component. *Cognition, 85*(2), 189-196.

Rossion, B., & Jacques, C. (2008). Does physical interstimulus variance account for early electrophysiological face sensitive responses in the human brain? Ten lessons on the N170. *Neuroimage, 39*(4), 1959-1979.

Rossion, B., Kung, C. C., & Tarr, M. J. (2004). Visual expertise with nonface objects leads to competition with the early perceptual processing of faces in the human occipitotemporal cortex. *Proceedings of the National Academy of Sciences of the United States of America, 101*(40), 14521-14526.

Rotshtein, P., Geng, J. J., Driver, J., & Dolan, R. J. (2007). Role of features and second-order spatial relations in face discrimination, face recognition, and individual face skills: Behavioral and functional magnetic resonance imaging data. *Journal of Cognitive Neuroscience, 19*(9), 1435-1452.

Rubin, N., Nakayama, K., & Shapley, R. (1997). Abrupt learning and retinal size specificity in illusory-contour perception. *Current Biology, 7*(7), 461-467.

Russell, R., Chatterjee, G., & Nakayama, K. (2012). Developmental prosopagnosia and super-recognition: No special role for surface reflectance processing. *Neuropsychologia, 50*(2), 334-340.

Russell, R., Duchaine, B., & Nakayama, K. (2009). Super-recognizers: People with extraordinary face recognition ability. *Psychonomic Bulletin & Review, 16*(2), 252-257.

Ryan, J. D., Althoff, R. R., Whitlow, S., & Cohen, N. J. (2000). Amnesia is a deficit in relational memory. *Psychological Science, 11*(6), 454-461.

Sandman, C. A. (1993). Memory rehabilitation in Alzheimer's disease: Preliminary findings. *Clinical Gerontologist, 13*(4), 19-33.

Sangals, J., Ross, L., & Sommer, W. (2004). Time pressure effects on information processing in overlapping tasks: evidence from the lateralized readiness potential. *Acta Psychologica, 117*(3), 275-294.

Sangals, J., Wilwer, M., & Sommer, W. (2007). Localizing practice effects in dual-task performance. *Quarterly Journal of Experimental Psychology, 60*(6), 860-876.

Sanquist, T. F., Rohrbaugh, J. W., Syndulko, K., & Lindsley, D. B. (1980). Electrocortical signs of levels of processing – perceptual analysis and recognition memory. *Psychophysiology, 17*(6), 568-576.

Schacter, D. L. (1990). PERCEPTUAL REPRESENTATION SYSTEMS AND IMPLICIT MEMORY - TOWARD A RESOLUTION OF THE MULTIPLE MEMORY-SYSTEMS DEBATE. *Annals of the New York Academy of Sciences, 608*, 543-571.

Schendan, H. E., Ganis, G., & Kutas, M. (1998). Neurophysiological evidence for visual perceptual categorization of words and faces within 150 ms. *Psychophysiology, 35*(3), 240-251.

Schmiedek, F., Li, S. C., & Lindenberger, U. (2009). Interference and Facilitation in Spatial Working Memory: Age-Associated Differences in Lure Effects in the N-Back Paradigm. *Psychology and Aging, 24*(1), 203-210.

Schmiedek, F., Lövdén, M., & Lindenberger, U. (2010). Hundred days of cognitive training enhance broad cognitive abilities in adulthood: Findings from the COGITO study. *Frontiers in Aging Neuroscience, 2*, 1-10.

Schweinberger, S. (1996). How Gorbachev primed Yeltsin: Analyses of associative priming in person recognition by means of reaction times and event-related brain potentials. *Journal of Experimental Psychology-Learning Memory and Cognition, 22*(6), 1383-1407.

Schweinberger, S. (2011). Neurophysiological Correlates of Face Recognition. In A. J. Calder, G. Rhodes, M. H. Johnson & J. V. Haxby (Eds.), *The Oxford Handbook of Face Perception*. New York: Oxford University Press.

Schweinberger, S., & Burton, A. M. (2003). Covert recognition and the neural system for face processing. *Cortex, 39*(1), 9-30.

Schweinberger, S., Huddy, V., & Burton, A. M. (2004). N250r: a face-selective brain response to stimulus repetitions. *Neuroreport, 15*(9), 1501-1505.

Schweinberger, S., Pfutze, E. M., & Sommer, W. (1995). Repetition Priming and Associative Priming of Face Recognition - Evidence from Event-Related Potentials. *Journal of Experimental Psychology-Learning Memory and Cognition, 21*(3), 722-736.

Schweinberger, S., Pickering, E. C., Burton, A. M., & Kaufmann, J. M. (2002). Human brain potential correlates of repetition priming in face and name recognition. *Neuropsychologia, 40*(12), 2057-2073.

Schweinberger, S., Pickering, E. C., Jentzsch, I., Burton, A. M., & Kaufmann, J. M. (2002). Event-related brain potential evidence for a response of inferior temporal cortex to familiar face repetitions. *Cognitive Brain Research, 14*(3), 398-409.

Scott, L. S., Tanaka, J. W., Sheinberg, D. L., & Curran, T. (2006). A reevaluation of the electrophysiological correlates of expert object processing. *Journal of Cognitive Neuroscience, 18*(9), 1453-1465.

Scott, L. S., Tanaka, J. W., Sheinberg, D. L., & Curran, T. (2008). The role of category learning in the acquisition and retention of perceptual expertise: A behavioral and neurophysiological study. *Brain Research, 1210*, 204-215.

Sekiguchi, T. (2011). Individual differences in face memory and eye fixation patterns during face learning. *Acta Psychologica, 137*(1), 1-9.

Shipstead, Z., Redick, T. S., & Engle, R. W. (2012). Is Working Memory Training Effective? *Psychological Bulletin, 138*(4), 628-654.

Shiran, A., & Breznitz, Z. (2011). The effect of cognitive training on recall range and speed of information processing in the working memory of dyslexic and skilled readers. *Journal of Neurolinguistics, 24*(5), 524-537.

Sigman, M., & Gilbert, C. D. (2000). Learning to find a shape. *Nature Neuroscience, 3*(3), 264-269.

Skinner, E. I., & Fernandes, M. A. (2009). Illusory Recollection in Older Adults and Younger Adults Under Divided Attention. *Psychology and Aging, 24*(1), 211-216.

Smith, G. E., Housen, P., Yaffe, K., Ruff, R., Kennison, R. F., Mahncke, H. W., et al. (2009). A Cognitive Training Program Based on Principles of Brain Plasticity: Results from the Improvement in Memory with Plasticity-based Adaptive Cognitive Training (IMPACT) Study. *Journal of the American Geriatrics Society, 57*(4), 594-603.

Sporer, S. L. (1991). Deep Deeper Deepest - Encoding Strategies and the Recognition of Human Faces. *Journal of Experimental Psychology-Learning Memory and Cognition, 17*(2), 323-333.

Sporer, S. L. (1992). *Das Wiedererkennen von Gesichtern*. Weinheim: Psychologie Verlags Union.

Stahl, J., Wiese, H., & Schweinberger, S. (2010). Learning task affects ERP-correlates of the own-race bias, but not recognition memory performance. *Neuropsychologia, 48*(7), 2027-2040.

Stekelenburg, J. J., & de Gelder, B. (2004). The neural correlates of perceiving human bodies: an ERP study on the body-inversion effect. *Neuroreport, 15*(5), 777-780.

Stelmack, R. M., & Beauchamp, C. M. (2006). The chronometry of mental ability: An event-related potential analysis of an auditory oddball discrimination task. *Intelligence, 34*(6), 571-586.

Tacikowski, P., Jednorog, K., Marchewka, A., & Nowicka, A. (2011). How multiple repetitions influence the processing of self-, famous and unknown names and faces: An ERP study. *International Journal of Psychophysiology, 79*(2), 219-230.

Tam, S. F., & Man, W. K. (2004). Evaluating computer-assisted memory retraining programmes for people with post-head injury amnesia. *Brain Injury, 18*(5), 461-470.

Tanaka, J. W., Curran, T., Porterfield, A. L., & Collins, D. (2006). Activation of preexisting and acquired face representations: The N250 event-related potential as an index of face familiarity. *Journal of Cognitive Neuroscience, 18*(9), 1488-1497.

Tanaka, J. W., Curran, T., & Sheinberg, D. L. (2005). The training and transfer of real-world perceptual expertise. *Psychological Science, 16*(2), 145-151.

Tanaka, J. W., & Pierce, L. J. (2009). The neural plasticity of other-race face recognition. *Cognitive Affective & Behavioral Neuroscience, 9*(1), 122-131.

Thierry, G., Martin, C. D., Downing, P., & Pegna, A. J. (2007). Controlling for interstimulus perceptual variance abolishes N170 face selectivity. *Nature Neuroscience, 10*(4), 505-511.

Thompson, G. (2005). Cognitive-training programs for older adults: What are they and can they enhance mental fitness? *Educational Gerontology, 31*(8), 603-626.

van der Lubbe, R. H. J., Jaskowski, P., Wauschkuhn, B., & Verleger, R. (2001). Influence of time pressure in a simple response task, a choice-by-location task, and the Simon task. *Journal of Psychophysiology, 15*(4), 241-255.

Verleger, R. (1997). On the utility of P3 latency as an index of mental chronometry. *Psychophysiology, 34*(2), 131-156.

Wagner, U., Kashyap, N., Diekelmann, S., & Born, J. (2007). The impact of post-learning sleep vs. wakefulness on recognition memory for faces with different facial expressions. *Neurobiology of Learning and Memory, 87*(4), 679-687.

Wang, R. S., Li, J. G., Fang, H. Z., Tian, M. Q., & Liu, J. (2012). Individual Differences in Holistic Processing Predict Face Recognition Ability. *Psychological Science, 23*(2), 169-177.

Weiner, B. (2000). Intrapersonal and Interpersonal Theories of Motivation from an Attributional Perspective *Educational Psychology Review, 12*(1), 1-14.

Wiese, H., & Daum, I. (2006). Frontal positivity discriminates true from false recognition. *Brain Research, 1075*(1), 183-192.

Wilhelm, O., Herzmann, G., Kunina, O., Danthiir, V., Schacht, A., & Sommer, W. (2010). Individual differences in perceiving and recognizing faces—One element of social cognition. *Journal of Personality and Social Psychology, 99*(3), 530-548.

Willis, S. L., & Nesselroade, C. S. (1990). Long-term effects of fluid ability training in old-old age. *Developmental Psychology, 26*(6), 905-910.

Willis, S. L., Tennstedt, S. L., Marsiske, M., Ball, K., Elias, J., Koepke, K. M., et al. (2006). Long-term effects of cognitive training on everyday functional outcomes in older adults. *Jama-Journal of the American Medical Association, 296*(23), 2805-2814.

Wilmer, J. B., Germine, L., Chabris, C. F., Chatterjee, G., Williams, M., Loken, E., et al. (2010). Human face recognition ability is specific and highly heritable. *Proceedings of the National Academy of Sciences of the United States of America, 107*(11), 5238-5241.

Wolk, D. A., Schacter, D. L., Lygizos, M., Sen, N. M., Holcomb, P. J., Daffner, K. R., et al. (2006). ERP correlates of recognition memory: Effects of retention interval and false alarms. *Brain Research, 1096*, 148-162.

Wölwer, W., Frommann, N., Halfmann, S., Piaszek, A., Streit, M., & Gaebel, W. (2005). Remediation of impairments in facial affect recognition in schizophrenia: efficacy and specificity of a new training program. *Schizophr.Res., 80*(2-3), 295-303.

Wong, A. C. N., Palmeri, T. J., & Gauthier, I. (2009). Conditions for Facelike Expertise With Objects: Becoming a Ziggerin Expert-but Which Type? *Psychological Science, 20*(9), 1108-1117.

Woodhead, M. M., Baddeley, A. D., & Simmonds, D. C. V. (1979). Training People to Recognize Faces. *Ergonomics, 22*(3), 333-343.

Yang, L. X., & Krampe, R. T. (2009). Long-term Maintenance of Retest Learning in Young Old and Oldest Old Adults. *Journals of Gerontology Series B-Psychological Sciences and Social Sciences, 64*(5), 608-611.

Yang, L. X., Krampe, R. T., & Baltes, P. B. (2006). Basic forms of cognitive plasticity extended into the oldest-old: Retest learning, age, and cognitive functioning. *Psychology and Aging, 21*(2), 372-378.

Yardley, L., McDermott, L., Pisarski, S., Duchaine, B., & Nakayama, K. (2008). Psychosocial consequences of developmental prosopagnosia: A problem of recognition. *Journal of Psychosomatic Research, 65*(5), 445-451.

Yi, D. J., Olson, I. R., & Chun, M. M. (2006). Shape-specitic perceptual learning in a figure-ground segregation task. *Vision Research, 46*(6-7), 914-924.

Young, A. W., & Bruce, V. (2011). Understanding person perception. *British Journal of Psychology, 102*, 959-974.

Zhu, Q., Song, Y., Hu, S., Li, X., Tian, M., Zhen, Z., et al. (2010). Heritability of the Specific Cognitive Ability of Face Perception. *Current Biology, 20*(2), 137-142.

ERKLÄRUNGEN

Hiermit versichere ich, dass ich die Dissertation selbständig und ohne unerlaubte Hilfe angefertigt habe. Ich habe die Dissertation an keiner anderen Universität eingereicht und besitze keinen Doktorgrad im oben genannten Fach.

Die Promotionsordnung der Mathematisch-Naturwissenschaftlichen Fakultät II vom 17.01.2005, zuletzt geändert am 13.02.2006, veröffentlicht im Amtlichen Mitteilungsblatt der HU Nr. 34/2006, ist mir bekannt.