The Gaze-Contingent Learning Task:
How Infants, Younger, and Older Adults,
Learn to Control their Visual Environment with
Looking Behavior in Experimental Research

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Zusammenfassung

Eye-Tracking bezeichnet das Messen und Aufzeichnen der Blickbewegungen einer Person. Historisch gesehen basiert Eye-Tracking auf Beobachtungen des Testleiters, der das Blickverhalten der Probanden während des Versuchsablaufes oder die Videoaufzeichnung des Blickverhaltens eines Probanden in einer Testsituation kodierte. Dabei konnte allerdings nur die Blickrichtung des Probanden erhoben werden. Heutzutage ist es jedoch möglich, aufgrund neuerer, automatisierter Eye-Tracking-Techniken detailliertere Blickbewegungen, wie z.B. Fixationen und Sakkaden, zu messen. Diese Verbesserung der Eye-Tracking-Technik ermöglicht nicht nur passives Eye-Tracking, sondern auch aktives Blickkontingenz-Eye-Tracking. Passives Eye-Tracking bezeichnet das Messen und Aufzeichnen des Blickverhaltens, um herauszufinden, wo der Proband hinschaut. Im Gegensatz dazu erhebt das aktive Blickkontingenz-Eye-Tracking nicht nur, wo ein Proband hinschaut, sondern ermöglicht dem Probanden auch, die Stimuli, die auf einem Bildschirm präsentiert werden, aktiv zu verändern oder zu kontrollieren. Dabei wird das Blickverhalten online kodiert, und spezifisches Blickverhalten ist an eine kontingente Veränderung der Stimuli auf dem Bildschirm gekoppelt. Deshalb kann das aktive Blickkontingenz-Eye-Tracking eingesetzt werden, um den Probanden aktive Kontrolle über ihre visuelle Umwelt zu ermöglichen.

In der psychologischen Forschung ist Eye-Tracking ein wichtiges Forschungs-instrument, da das Blickverhalten in spezifischen Eye-Tracking-Aufgaben genutzt werden kann, um Aufschluss über kognitive Prozesse, wie z.B. Aufmerksamkeit, Lernen und Gedächtnis, zu gewinnen. Unterschiedliche passive und aktiv-blickkontingente Eye-Tracking-Aufgaben wurden entwickelt, um eine Vielzahl an kognitiven Prozessen im Erwachsenen- und Säuglingsalter zu untersuchen. Diese Aufgaben sind besonders wichtig in der Säuglingsforschung, da es in diesem Alter schwierig ist, kognitive Prozesse zu untersuchen. Dies hängt damit zusammen, dass es sich um eine präverbale Stichprobe, die nur über ein limitiertes motorisches Repertoire verfügt, handelt. Obwohl kognitive Prozesse von Erwachsenen anhand verbaler oder anderer motorischer Aufgaben untersucht werden können, werden passive und aktiv-blickkontingente Eye-Tracking-Aufgaben regelmäßig in dieser Altersgruppe eingesetzt, da sie zusätzliche Informationen über kognitive Prozesse liefern können. Neben der Möglichkeit zur Untersuchung von kognitiven Prozessen bieten aktiv-blickkontingente Eye-Tracking-Aufgaben den Probanden auch die Gelegenheit, ihre visuelle Umwelt aktiv zu kontrollieren. Dennoch werden aktiv-blickkontingente Eye-Tracking-Aufgaben nur selten eingesetzt, um Probanden visuelle Kontrolle über ihre Umwelt zu verschaffen.

Bis jetzt wurden aktiv-blickkontingente Eye-Tracking-Aufgaben zur Kontrolle der visuellen Umwelt nur bei Erwachsenen, aber noch nicht bei Säuglingen eingesetzt. Da diese Aufgaben jedoch auch für Säuglinge und Kleinkinder geeignet sind, besteht die Möglichkeit, diese Methode über die gesamte Lebenspanne hinweg anzuwenden. Somit kann das Erlernen des Kontrollierens der Umwelt durch Blickverhalten über die gesamte Lebensspanne untersucht werden.

Die vorliegende Dissertation hat sich genau dies zum Ziel gesetzt. Um dieses Ziel zu erreichen, wurde eine neue aktiv-blickkontingente Eye-Tracking-Aufgabe entwickelt, die sogenannte gaze-contingent learning task (GCLT). Im Wesentlichen ist die GCLT eine operante Konditionierungsaufgabe, bei der sich Probanden Kontrolle über ihre visuelle Umwelt aneignen, indem sie eine bestimmte blickkontingente Assoziation zwischen ihrem Blickverhalten und einem visuellen Effekt erlernen. Die in dieser Dissertation verwendete GCLT umfasst zwei Hauptversionen: zum einen die sog. one disc GCLT, und zum anderen die two discs GCLT. In der one disc GCLT wird ein Kreis auf der rechten Bildschirmseite gezeigt. Jedes Mal, wenn der Proband auf diesen Kreis schaut, erscheint ein Stimulus auf der linken Bildschirmseite. Somit kommt dem Kreis eine Schalterfunktion zu. In der two discs GCLT ist sowohl am rechten als auch am linken Bildschirmrand ein Kreis zu sehen. Hier kommt nur jeweils einem der beiden Kreise die Schalterfunktion zu. Um ihre visuelle Umwelt zu kontrollieren, müssen Probanden innerhalb der one disc GCLT die blickkontingente Assoziation zwischen ihren Blicken auf den Kreis und dem Erscheinen eines Stimulus erlernen, während sie in der two discs GCLT außerdem noch lernen müssen, zwischen dem Kreis mit und dem Kreis ohne Schalterfunktion zu unterscheiden.

Um also die Erlernbarkeit der visuellen Kontrolle über die Umwelt im Verlauf der Lebensspanne zu erfassen, wurden in dieser Dissertation Säuglinge, jüngere und ältere Erwachsene im Rahmen von GCLT-Experimenten untersucht. Altersunterschiede ergeben sich dabei zum einen hinsichtlich der Erfassung des blickkontingenten Assoziationslernens. Bei Säuglingen kann das blickkontingente Assoziationslernen nur mittels Blickverhalten, bei Erwachsenen hingegen auch verbal erhoben werden. Mit Hilfe des Blickverhaltens, das während einer GCLT gemessen wird, kann gezeigt werden, dass eine einfache Assoziation zwischen dem Blick auf einen Kreis und dem Erscheinen eines visuellen Effektes gelernt wurde. Das Blickverhalten bietet allerdings keine Information darüber, ob höhere kognitive Prozesse beim blickkontingenten Assoziationslernen eine Rolle spielen, d.h. ob Säuglinge dabei auch bewusst lernen, dass ihr eigenes Blickverhalten den Effekt verursacht. Dieses bewusste Lernen kann dafür aber verbal erfasst werden. Wenn ein Erwachsener die

blickkontingente Assoziation zwischen dem eigenen Blickverhalten und dem Erscheinen des Stimulus verbalisieren kann bedeutet dies, dass der Proband die Assoziation nicht nur mechanistisch, sondern auch bewusst gelernt hat. Letzteres impliziert die Anwendung höherer kognitiver Prozesse.

Des Weiteren können auch Altersunterschiede bezüglich der Lern- und Wahrnehmungsprozesse, die dem blickkontingenten Assoziationslernen zu Grunde liegen bzw. daran beteiligt sind, angenommen werden. In Bezug auf die Lernprozesse kann vermutet werden, dass je nach Altersgruppe und deren kognitivem Entwicklungsstand, unterschiedliche Lernprozesse maßgeblich zum blickkontingenten Assoziationslernen beitragen. Bei Säuglingen könnte eine untergeordnete Rolle höherer kognitiver Prozesse beim blickkontingenten Assoziationslernen erwartet werden, da diese in dieser Altersgruppe erst in der Entwicklung begriffen sind, während mechanistischen Prozessen eine größere Rolle zukommen könnte. Im Gegensatz dazu kann bei jüngeren Erwachsenen von einer stärkeren Beteiligung höherer kognitiver Prozesse ausgegangen werden, da diese in dieser Altersgruppe voll entwickelt sind. Bei älteren Erwachsenen wiederum ist bei bestimmten kognitiven Fähigkeiten, den sog. „mechanics", die z.B. Prozesse der Informationsverarbeitung und Problemlösung umfassen, von altersbedingten Einbußen auszugehen. Hingegen sind andere kognitive Fähigkeiten, die sog. „pragmatics", welche z.B. über die Lebensspanne erworbenes Wissen und Erfahrungen beinhalten, davon nicht betroffen. Folglich wäre bei älteren Erwachsenen eine höhere Bedeutung von „pragmatics" im Gegensatz zu „mechanics" für blickkontingentes Assoziationslernen zu erwarten.

In Bezug auf die Wahrnehmungsprozesse kann eine Bedeutung sowohl von Bottom-Up- als auch von Top-Down-Prozessen beim blickkontingenten Assoziationslernen angenommen werden. Während Bottom-Up-Prozesse situationsbezogene Information zur Interpretation der sensorischen Wahrnehmung nutzen, nutzen Top-Down-Prozesse hierzu bereits vorhandenes Vorwissen. Im Laufe der Entwicklung häufen Menschen mehr und mehr Wissen an, weswegen davon ausgegangen werden kann, dass mit zunehmendem Alter Top-Down-Prozesse mehr und mehr an Bedeutung für das blickkontingente Assoziationslernen gewinnen.

In der vorliegenden Dissertation wurden drei unterschiedliche Experimentalreihen mit one und two disc(s) GCLT- Experimenten durchgeführt, um herauszufinden inwiefern Säuglinge sowie jüngere und ältere Erwachsene die blickkontingente Assoziation innerhalb der GCLT lernen. Diese Experimente sollen zum einen zeigen, ob unterschiedliche

Altersgruppe in der Lage sind, die blickkontingente Assoziation innerhalb der GCLT überhaupt zu lernen und inwiefern dahingehend altersbezogene Unterschiede bestehen. Des Weiteren sollen diese Experimente die Möglichkeit eröffnen Altersunterschiede in Lern- und Wahrnehmungsprozessen, die am blickkontingenten Assoziationslernen beteiligt sind, zu diskutieren.

In einer ersten Experimentalreihe wurde erstmalig untersucht ob Säuglinge und Erwachsene eine solche blickkontingente Assoziation innerhalb der GCLT lernen können. Dazu wurde eine one disc GCLT mit Säuglingen (Experiment 1) und eine two discs GCLT mit Säuglingen und Erwachsenen (Experiment 2) durchgeführt. In Experiment 1 wurden sechs und acht Monate alte Säuglinge getestet, wobei einem roten Kreis die Schalterfunktion in der one disc GCLT zukam. Der Stimulus wurde nach Aktivierung der Schalterfunktion für 1.5 s gezeigt. Die Ergebnisse des Blickverhaltens der Säuglinge in Experiment 1 zeigen, dass diese häufig auf den roten Kreis schauen und den neuen Stimulus antizipieren. Daraus kann man schließen, dass die Säuglinge die blickkontingente Assoziation zwischen dem Blick auf den Kreis und dem Erscheinen des Stimulus in der one disc GCLT gelernt haben. Da die Ergebnisse nur anhand des Blickverhaltens gefunden wurden, bleibt jedoch offen ob die Säuglinge gelernt haben, dass ihr eigenes Blickverhalten das Erscheinen des Stimulus verursacht hat. In Experiment 2 wurden sechs und acht Monate alte Säuglinge sowie junge Erwachsene in einer two discs GCLT mit roten Kreisen getestet. Anders als in der one disc GCLT verschwanden die Stimuli, die in dieser two discs GCLT präsentiert wurden, nicht nach 1.5 s sondern verblassten innerhalb von ungefähr 17 s kontinuierlich. Die Ergebnisse des Blickverhaltens der Säuglinge in Experiment 2 zeigen, dass diese häufig auf den funktionierenden roten Kreis schauen, und der funktionierende Kreis auch öfter angeschaut wird als der nichtfunktionierende Kreis. Wie in Experiment 1 weisen diese Befunde darauf hin, dass die Säuglinge die blickkontingente Assoziation zwischen dem Blick auf den funktionierenden Kreis und dem Erscheinen des Stimulus in der two discs GCLT gelernt haben. Überraschenderweise legen die Ergebnisse von Experiment 2 aber auch nahe, dass die gleiche Assoziation für junge Erwachsene schwierig zu erlernen ist. Es zeigt sich, dass nur 36% der jungen Erwachsenen verbalisieren können, dass ihr eigenes Blickverhalten das Erscheinen des Stimulus verursacht hat (Solvers), während die restlichen 64% dies nicht können (Non-Solvers). Ebenfalls wurde ein Zusammenhang zwischen der Verbalisierung der blickkontingenten Assoziation und spezifischem Blickverhalten gefunden. Im Gegensatz zu Non-Solvern, schauen Solvers sowie Säuglinge häufiger auf den funktionierenden als auf den nichtfunktionierenden Kreis. Daher weisen Experiment 1 und 2 darauf hin, dass Säuglinge die

blickkontingente Assoziation innerhalb einer GCLT relativ leicht lernen, während dies für Erwachsene schwieriger ist.

In einer zweiten Experimentalreihe wurde das Erlernen der blickkontingenten Assoziation innerhalb der two discs GCLT mit Erwachsenen weiter erforscht. Dabei wurden unterschiedliche Wahrnehmungsfaktoren, die blickkontingentes Assoziationslernen beeinflussen können, untersucht. In Experiment 3 wurde erfasst inwiefern der situationsbezogene Faktor Kontiguität (Latenzzeit zwischen dem Blick auf den funktionierenden Kreis und dem Erscheinen des Stimulus) das Erlernen der blickkontingenten Assoziation innerhalb der two discs GCLT mit roten Kreisen bei jungen Erwachsenen beeinflusst. Die Ergebnisse weisen drauf hin, dass Kontiguität das Blickverhalten der jungen Erwachsenen beeinflusst, nicht aber die Verbalisierung der gelernten Assoziation. Unabhängig von der Kontiguitätsbedingung (kurz vs. lang) war es für junge Erwachsene schwierig die blickkontingente Assoziation zwischen dem Blick auf den funktionierenden Kreis und dem Erscheinen des Stimulus in der two discs GCLT zu lernen. In Experiment 4 wurde untersucht ob Vorwissen das Erlernen der blickkontingenten Assoziation innerhalb der two discs GCLT bei jüngeren und älteren Erwachsenen beeinflusst. In diesem Experiment wurden jüngere und ältere Erwachsene in unterschiedliche Versionen des two discs GCLT getestet. Die roten Kreise wurden durch grüne Kreise bzw. graue Schalter ersetzt, um vorwissensbezogene Hinweise zu implementieren. Die Ergebnisse zeigen, dass ein kleinerer Anteil der älteren als der jüngeren Erwachsenen die blickkontingente Assoziation verbalisieren kann. Weiterhin zeigen die Ergebnisse, dass vorwissensbezogene Hinweise älteren Erwachsenen das bewusste Lernen der blickkontingenten Assoziation erleichtern, während diese Hinweise bei jüngeren Erwachsenen keinen Effekt haben. Dies weist darauf hin, dass ältere Erwachsene beim bewussten Lernen der blickkontingenten Assoziation innerhalb der two discs GCLT abhängiger von Vorwissen sind als jüngere Erwachsene.

In einer dritten Experimentalreihe wurde das Lernen der blickkontingenten Assoziation innerhalb der one disc GCLT mit Säuglingen untersucht. Der Fokus lag dabei nicht auf dem Lernen der blickkontingenten Assoziation in der GCLT an sich. Vielmehr wurde untersucht ob die one disc GCLT benutzt werden kann um Säuglingen in einer passiven Aufgabe, in der sie normalerweise kein Kontrolle haben, doch Kontrolle über ihre visuelle Umwelt zu geben. Um dies zu testen wurden ein passives Habituations-Dishabituations-Experiment (Experiment 5) und ein aktiv-blickkontingentes Habituations-Dishabituations-Experiment (Experiment 6) mit Säuglingen durchgeführt. In beiden Habituations-Dishabituations-Experimenten wurden Gesichter als Stimuli benutzt. Der

Vergleich beider Experimente zeigt, dass die one disc GCLT benutzt werden kann, um das Habituations-Dishabituations-Lernen von Säuglingen in einer Weise zu untersuchen, in der die Säuglinge visuelle Kontrolle über ihre Umwelt haben. Es konnte gezeigt werden, dass Säuglinge innerhalb einer one disc GCLT zur Habituation in der Lage sind. Die Ergebnisse könnten darauf hindeuten, dass die Säuglinge lernten auf den Kreis zu schauen, wenn ihr Interesse am dargebotenen Stimulus abnahm. Des Weiteren zeigt dieser Vergleich, dass aktive Kontrolle über die visuelle Umwelt wie sie durch die GCLT ermöglicht wird, das Habituations-Dishabituations-Lernen der Säuglinge beeinflussen könnte. Hierauf weisen Unterschiede in der Dishabituation von Säuglingen zwischen der passiven und der aktiv-blickkontingenten Habituations-Dishabituationsaufgabe hin. Die Ergebnisse legen nahe, dass das Wiedererkennungsgedächtnis der Säuglinge durch die aktive Kontrolle über den visuellen Stimulus in einer Habituations-Dishabituations-Aufgabe beeinflusst werden kann.

Insgesamt kann aus den Ergebnissen der durchgeführten Experimente geschlussfolgert werden, dass die GCLT benutzt werden kann, um Personen unterschiedlicher Altersstufen mittels Blickverhalten Kontrolle über ihre visuelle Umwelt zu verschaffen. In den Experimenten wurde gezeigt, dass Säuglinge, jüngere und ältere Erwachsene in der Lage sind blickkontingente Assoziationen in GCLT-Versuchsanordnungen zu lernen. Allerdings wurden auch entwicklungsbedingte Unterschiede beim Lernen blickkontingenter Assoziationen gefunden. Zum einen zeigte sich anhand des Blickverhaltens, dass Säuglinge solche blickkontingenten Assoziationen sehr leicht lernen. Gleichzeitig weisen Blickverhalten und Verbalisierbarkeit der blickkontingenten Assoziation darauf hin, dass das Erlernen derselben für Erwachsene schwierig ist, insbesondere für ältere Erwachsene.

Die beim Lernen blickkontingenter Assoziationen gefundenen Altersunterschiede können durch entwicklungsbedingte Unterschiede in den beteiligten Lern- und Wahrnehmungsprozessen erklärt werden. Mechanistische Lernprozesse und das Fehlen von Vorwissen könnten das blickkontingente Assoziationslernen für Säuglinge leicht gemacht haben. Die entwicklungsbedingte Zunahme höherer kognitiver Prozesse und vor allem der Zugewinn an Vorwissen, das mit der zu lernenden Assoziation nicht zwingend kongruent sein muss, könnte jungen, insbesondere aber älteren Erwachsenen das blickkontingente Assoziationslernen erschwert haben.

Aus den vorliegenden Ergebnissen kann weiterer Forschungsbedarf abgeleitet werden, der mit aktiv-blickkontingenten Eye-Tracking-Aufgaben für das Säuglings- und Erwachsenenalter sowie über die gesamte Lebensspanne hinweg untersucht werden kann.

Chapter 1

Dissertation Outline

Eye tracking, i.e., the measuring and recording of *looking behavior*, provides information on where someone is looking at a particular moment. Historically, eye tracking relied on observations made by human coders of where a subject is looking or on manual coding of videotaped looking behavior. However, with the invention of newer eye tracking techniques it became possible to automatically assess looking behavior. Such advances in eye tracking techniques made it possible to make more detailed analyses of looking behavior. Nowadays, not only the direction of looking but also the exact location of *fixations* and *saccades* can be measured. Moreover, advances in eye tracking techniques have also made it possible to apply eye tracking in an active gaze-contingent instead of in a passive manner. *Passive eye tracking* is the measuring and recording of looking behavior to investigate what is looked at. In contrast, *active gaze-contingent eye tracking* does not only measure where a subject looks, however, it also provides the opportunity to change or control the stimuli that are presented on the display screen. Here, looking behavior is coded online and specific looking behavior is coupled to a contingent change within the stimuli presented on the display screen. Therefore, active gaze-contingent eye tracking can be applied to give subjects *active control* over their visual environment.

Within *psychological research* eye tracking is an important research tool as looking behavior within specific *looking behavior tasks* can be used to make inferences about *cognitive processes* such as *attention*, *learning*, and *memory*. Different *passive* and *active gaze-contingent looking behavior tasks* were developed to measure a variety of cognitive processes in *infancy* and *adulthood*. These tasks are especially important in infancy research as it is otherwise difficult to measure cognitive processes within such a preverbal sample that has limited motor repertoires. Although adults' cognitive processes can also be measured verbally or by other motor tasks, passive and active gaze-contingent looking behavior tasks are also frequently used within this age range as they might provide additional information about cognitive processes. Next to studying cognitive processes, active gaze-contingent looking behavior tasks can also be used to give subjects active control over their visual environment with looking behavior. Nevertheless, such tasks are only seldom applied with this intention.

Until now, such tasks have only been used to give adults, but not infants, active visual environment control. However, as such tasks are applicable to infants they provide the opportunity to make a *lifespan investigation* on how subjects of different ages learn to control their visual environment with looking behavior.

Within the present dissertation such a lifespan examination on how subjects of different ages learn to control their visual environment with looking behavior is made. In order to conduct this lifespan examination, a newly developed active gaze-contingent looking behavior task, i.e., the *gaze-contingent learning task* (*GCLT*), is introduced. In essence, the GCLT is an *operant conditioning learning task* in which subjects learn to control their visual environment with looking behavior by acquiring a gaze-contingent association between their looking behavior and a visual effect. Two main versions of the GCLT are used in this dissertation, i.e., the *one disc GCLT* and the *two discs GCLT*. In the one disc GCLT a disc is presented at the right side of the display screen and every time a subject looks at this disc a stimulus appears at the left side of the display screen. Here, subjects have to learn the association between looking at the disc and the appearance of a new stimulus. The two discs GCLT differs from the one disc GCLT in that not one but two discs are presented. These discs are presented at the left and right side of the display screen and only one of the two discs (within one session only left or right) has the function of triggering a new stimulus (functioning disc) that appears in the middle of the display screen. The other disc is non-functioning. Within the two discs GCLT subjects are only able to acquire the gaze-contingent association when they learn to differentiate between the functioning and non-functioning disc.

In order to gather information on how subjects of different ages learn to control their visual environment with looking behavior, infants and younger as well as older adults are tested in several GCLT experiments. Thereby, developmental differences arise in how infants' and adults' gaze-contingent association learning is measured. Infants' gaze-contingent association learning can only be assessed *behaviorally* by measuring looking behavior whereas adults' gaze-contingent association learning can also be assessed *verbally* by administering a questionnaire. Within the GCLT looking behavior might indicate that an association between looking at the disc and the visual effect is learned. However, it remains unclear if this behaviorally assessed gaze-contingent association learning reflects a *mechanistic process* in which subjects do not learn that an effect is produced by their own behavior (*unconscious learning*) or if this learning reflects the use of *higher cognitive processes* in which subjects might have learned that an effect is produced by their own behavior (*conscious learning*). On the contrary, verbally assessed gaze-contingent association

learning directly shows whether subjects learned the association between their own behavior and the effect consciously which also implies the use of higher cognitive processes.

Next to the age difference in how gaze-contingent association learning is assessed in infancy and adulthood, it can be argued that there are other developmental differences in gaze-contingent association learning. Theoretically, it is discussed that there are developmental differences in the underlying *learning processes* (mechanistic vs. higher cognitive processes) that contribute to and in the *perceptual processes* (*bottom-up processing* of *situational information* vs. *top-down processing* in which *prior knowledge* is used to interpret information) that are involved during gaze-contingent association learning.

In this dissertation various one and two disc(s) GCLT experiments with infants and younger as well as older adults are conducted. The main aim is to examine whether subjects of different ages are able to learn a gaze-contingent association within a GCLT set-up and to investigate if there are developmental differences. Moreover, these experiments provide the opportunity to discuss developmental differences in gaze-contingent association learning against the background of developmental differences in underlying learning processes that contribute to and in perceptual processes that are involved during this learning.

To this end, this dissertation first of all reviews the historical and methodological background of eye tracking (Chapter 2). Then, an overview of psychological eye tracking research is provided (Chapter 3). In this chapter different active and gaze-contingent looking behavior tasks that are applied to investigate cognitive processes in infancy and adulthood are discussed. Chapter 4 provides a detailed description of the present research project by both introducing the GCLT theoretically and methodologically. Theoretically, a review on operant conditioning learning in infancy and adulthood is provided.

Chapter 5 presents a first line of experiments in which it is for the first time investigated how infants and younger adults learn to control the visual environment with their looking behavior within the GCLT. In Experiment 1 it is thereby examined how infants learn a gaze-contingent association within the one disc GCLT. In Experiment 2 it is investigated how infants and younger adults learn a gaze-contingent association within the two discs GCLT.

Chapter 6 presents a second line of experiments (Experiment 3 and 4) in which the learning of the gaze-contingent association within the two discs GCLT is further investigated with adult subjects. In two experiments, perceptual factors that might influence gaze-contingent association learning are investigated. In Experiment 3 it is examined whether the

learning of the gaze-contingent association within the two discs GCLT by young adults is influenced by *contiguity* (situational information). In Experiment 4, the influence of *prior knowledge related cues* on learning the gaze-contingent association within the two discs GCLT by younger and older adults is tested.

In a third line of experiments (Chapter 7) the one disc GCLT is further tested with infants. The primary focus of this chapter is not on learning the gaze-contingent association per se, however, it is examined whether the one disc GCLT can be used to give infants active control in a passive looking behavior task in which they have normally no control. In this chapter it is investigated whether this control over the visual environment influences infants' *habituation-dishabituation learning*. Therefore, a passive habituation-dishabituation experiment (Experiment 5) is compared to a one disc GCLT habituation-dishabituation experiment (Experiment 6).

Last but not least, the dissertation ends (Chapter 8) with a general discussion on how infants as well as younger and older adults learn to control their visual environment with looking behavior within GCLT set-ups. Age differences are discussed and what might have contributed to developmental differences in this learning is theoretically addressed. Furthermore, suggestions for future research are provided.

Chapter 2

Eye Tracking: Historical and Methodological Background

Eye tracking is the measuring and recording of *looking behavior*. When using *eye tracking techniques* it is assessed where someone is looking at a particular moment. In this chapter a historical and methodological background about eye tracking is provided.

History of Eye Tracking Techniques

Over the years, the eye tracking techniques used to measure looking behavior changed and evolved from simple observations made by human coders to fully automatic eye tracking systems (for overviews of different eye tracking techniques see Duchowski, 2007; Richardson & Spivey, 2008a; Young & Sheena, 1975).

The simplest form of eye tracking is *observations made by human coders* where a person judges where a subject is looking. This coding of human looking behavior can be done online (live coding of subjects' eye movements) but also offline by coding videotapes of the eyes. Although human observation is a very commonly used eye tracking technique it also has limitations. The primary limitation of human observations is that coders are only able to make rough judgments on where subjects are looking. Aslin and McMurray (2004) argue that trained online and offline coders can only reliably judge looking behavior within one of three or four regions of a stimulus field. Furthermore, the coding of videotapes is extremely time consuming which constitutes another limitation (e.g., Aslin & McMurray, 2004).

Various automatic eye tracking techniques were developed to make more objective records of looking behavior. These automatic eye tracking techniques automatically measure and record subjects' eye movements. One of the first attempts was made by Delabarre (1898) who used a *contact lens procedure*. In a contact lens procedure a mechanical device mounted on a contact lens that is worn directly on the eye measures eye movements (e.g., Duchowski, 2007; Young & Sheena, 1975). In Delabarre's (1898) study a moulded cap with a hole big enough to look through was directly worn on a cocaine anesthetized eye. Attached to the cap was a wire which ran to a lever that was able to record horizontal eye movements on a smoked surface of a kymograph cylinder. Vertical eye movements could also be measured when the wire ran over a pulley (Delabarre, 1898). Although this first attempt provided valuable first insights about eye movement behavior (Richardson & Spivey, 2008a) the contact lens method is criticized because it is a very uncomfortable and intrusive procedure (Duchowski, 2007).

Other automatic eye tracking techniques that are less intrusive are electro-olculography and photo- or video-oculography. *Electro-oculography* is based on the finding that the position of the eyes can be measured by recording the skin's electric potential with electrodes placed around the eye (e.g., Duchowski, 2007; Young & Sheena, 1975). Electro-oculography measures the corneoretinal potential that exists between the front (cornea) and the back (retina) of an eye. When eye movements are made the corneoretinal potential changes and this can be recorded by electrodes placed around the eyes (Young & Sheena, 1975). Electrodes placed left and right of the eye measure horizontal eye movements whereas electrodes placed above and below the eye measure vertical eye movements (Furman & Wuyts, 2012).

Photo- or video-oculography is a group of automatic eye tracking techniques that is based on the recording of eye features (e.g., position of the limbus, shape of the pupil) or the corneal reflection of a light that falls on the eye with a photo or video film. Recordings obtained by these techniques can be evaluated either manually by coding of the recorded videos or automatically by computer programs (Duchowski, 2007). One of the first photo-oculography eye trackers was developed by Dodge and Cline (1901). In their set-up Dodge and Cline (1901) recorded the corneal reflection that fell through a horizontal slit in a camera (this camera was directed on the eyes) on a photographic plate behind the camera. As this plate moved, eye movements were recorded on the x-axis and session time was recorded on the y-axis (Richardson & Spivey, 2008a).

Although the eye tracking techniques discussed above are good methods to measure the direction of eye movements (position of the eyes relative to the head), they do not measure the exact eye gaze position in space. Automatic eye tracking techniques that allow one to measure exact eye gaze position in space are called point of regard methods (e.g., Duchowski, 2007; Young & Sheena, 1975). Probably, the most widely used automatic eye tracking technique that measures point of regard is the video-based corneal reflection method (Duchowski, 2007).

The *video-based corneal reflection technique* makes use of two optical characteristics of the eye, namely the pupil center and the corneal reflection. Once the eye tracking software has identified the pupil center and the corneal reflection the vector between them is measured and trigonometric calculations are used to measure the point of regard (e.g., Poole & Ball, 2005, p. 212). Figure 1 gives a schematic example of where the pupil center and corneal reflection (right eye) are when a person looks straight forward, to the left and up (for good

photographic examples see Richardson & Spivey, 2008a, p. 1030). This technique makes it possible to dissociate eye movements from modest head or body movements which allows for more accurate eye tracking measurements (e.g., Duchowski, 2007; Feng, 2011; Poole & Ball, 2005; Richardson & Spivey, 2008a). However, in order to calculate the exact point of regard the video-based corneal reflection technique relies on a good calibration procedure. Here, the relative position of the pupil center and corneal reflection are measured when a subject looks at a number of predefined places on the computer screen where a calibration target is presented. After the calibration is performed, the computer validates the calibration information by re-presenting the targets and determining whether the estimation of eye gaze position is close to the predefined position of the targets (e.g., Duchowski, 2007; Holmqvist et al., 2011).

Figure 1. Schematic example of where the pupil center (black circle) and corneal reflection (little white circle) are when a person (right eye) looks straight forward, to the left and up.

The corneal reflection is not the only reflection that can be produced by light on the eyes. Although the corneal reflection (also called first Purkinje image) is the brightest reflection, other reflections can also be measured. The dual Purkinje image eye tracker makes use of such an additional reflection. This eye tracker does not only measure the first but also the fourth Purkinje image which provides very accurate eye tracking measurements (e.g., Duchowski, 2007; Richardson & Spivey, 2008a). As with the video-based corneal reflection method a calibration procedure is necessary to calculate gaze direction with the dual Purkinje image technique.

A limitation of many of the above mentioned eye tracking techniques is that they often use chinrests or other head mounted systems to avoid measurement problems that occur because of major head or body movements. By now, technological advances in automatic eye tracking techniques have made head and body movements less disruptive. For example, remote eye tracking systems without head or chin stabilizations have been developed (e.g., Richardson & Spivey, 2008a). These eye tracking systems provide opportunities to also track

subjects where stabilization of the head is not suitable (e.g., infants). An example of such an eye tracker system is the SR Research Eyelink Remote 1000 eye tracker which is the corneal reflection eye tracker technique that is used for the experiments in this dissertation (Eyelink Remote 1000, 2005). The SR Research Eyelink Remote 1000 eye tracker is shown in Figure 2. The left side of Figure 2 shows an infant subject who sits in an infant seat placed on her mother's lap facing the eye tracker display screen and camera (inside the white rectangles). At the right side of Figure 2 it can be seen that the infant is tested without head stabilization. The infant is wearing a small target sticker on her head which is used to measure infant's distance from the camera. These distance measures are used to correct for head and body movements.
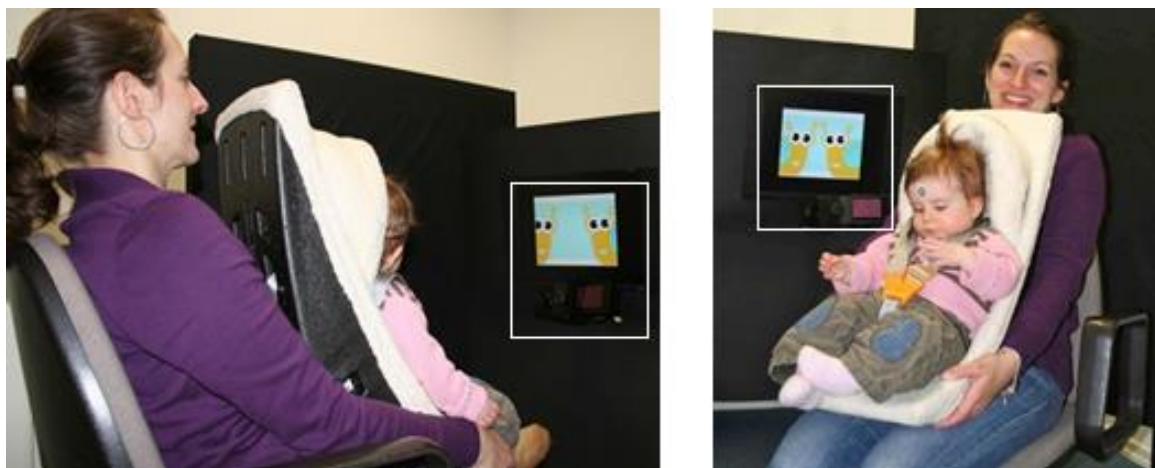
Figure 2. An infant sitting in an infant seat placed on her mother's lap in front of the SR Research Eyelink Remote 1000 eye tracker. The eye tracker display screen and camera are surrounded by white rectangles.

The Looking Behavior Measured

Advances in eye tracking techniques have made it possible to make more detailed analyses of looking behavior. Nowadays, not only the direction of looking behavior but also the exact gaze location can be measured. An example of such detailed looking behavior measured with a corneal reflection eye tracker (the SR Research Eyelink Remote 1000 eye tracker) is depicted in Figure 3. Here, the blue line indicates a subject's looking behavior on a face stimulus that is presented against a grey background. It can be seen that this subject primarily looks at the eyes, nose, and mouth of the face stimulus.
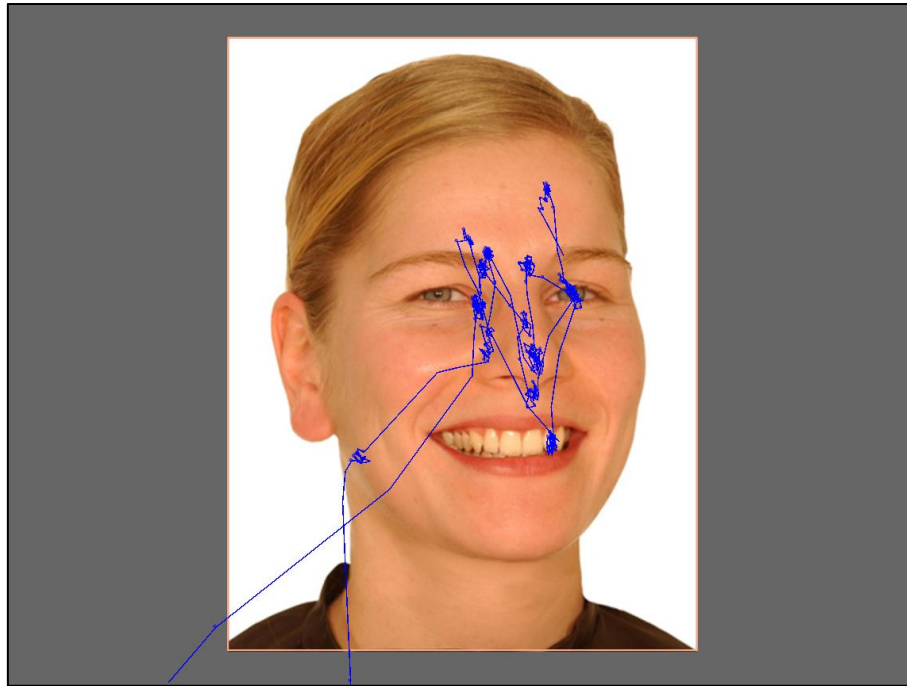
Figure 3. Example of a subject's looking behavior on a facial stimulus measured with the SR Research Eyelink Remote 1000 eye tracker.

The looking behavior depicted in Figure 3 can be divided into *fixations* and *saccades* which are illustrated in Figure 4. Within Figure 4 fixations are indicated by green circles. During a fixation, the eyes stay relative still and the fovea is stabilized on a single location (Duchowski, 2007). Fixations provide information on where a subject is looking at a particular moment. For instance, the duration of all fixations (total looking time) on the stimulus can be examined. With a corneal reflection eye tracker technique, not only is it possible to measure the total looking time on the whole stimulus but to also measure the duration of the fixations on separate areas of interest within the stimulus. Examples of this are the areas of interest created around the eyes or mouth (white rectangles) in Figure 4.
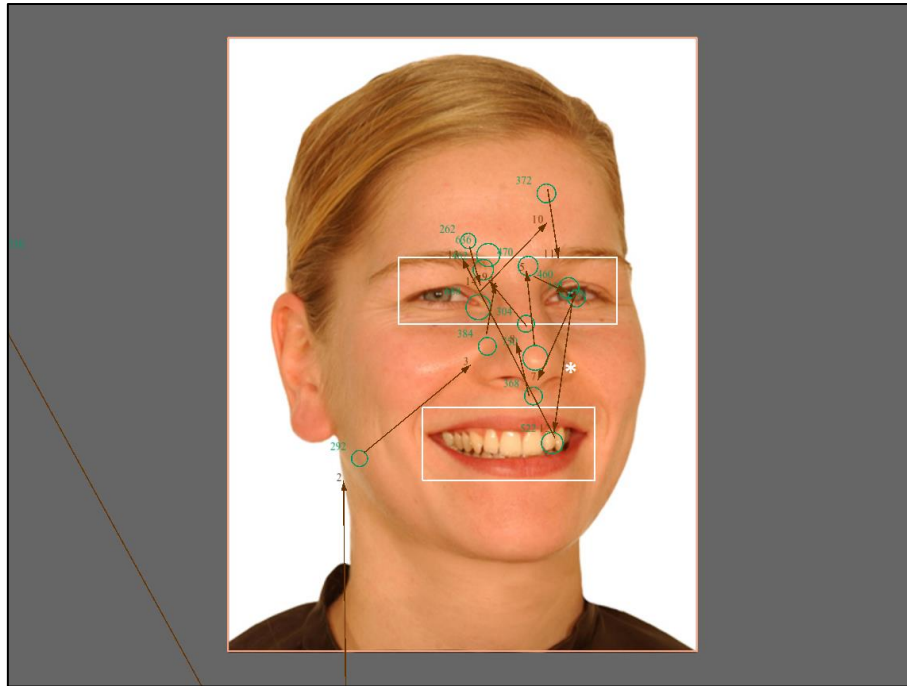
Figure 4. The same looking behavior as depicted in Figure 2 divided into fixations (green circles) and saccades (brown arrows). The white rectangles indicate areas of interest created around the eyes and mouth.

In Figure 4 saccades are indicated by brown arrows. Saccades are rapid eye movements (duration of approximately 10-100 ms) that occur between fixations. They can be made voluntary or be a reflex and are intended to direct the fovea to a new location (Duchowski, 2007). Because saccades are so rapid it is thought that the visual input from the eye to the brain is suppressed during this period (saccadic suppression in which no encoding takes place), and therefore it is thought that a person is effectively blind during saccades (e.g., Duchowski, 2007; Williams, 2013).

Together, fixations and saccades, form a sequence which is called a *scanpath* (e.g., Poole & Ball, 2005; Richardson, Dale, & Spivey, 2007; Williams, 2013). Scanpaths provide temporal information on what is looked at. In Figure 4 the direction of a saccade is indicated by the direction of the arrow. For example, the saccade indicated by the white star in Figure 4 started on the eye and ended on the mouth. Therefore, this subject first fixated on the eye before fixating the mouth.

The looking behavior data exemplified in Figure 3 and 4 can also be illustrated in a *heatmap*, see Figure 5. A heatmap provides information on which parts of the stimulus are more frequently fixated than others. In the heatmap presented in Figure 5 the red painted areas

are the most frequently fixated areas whereas the green or no color areas are less frequently fixated. Thus, heatmaps provide intuitive summaries of looking behavior data.
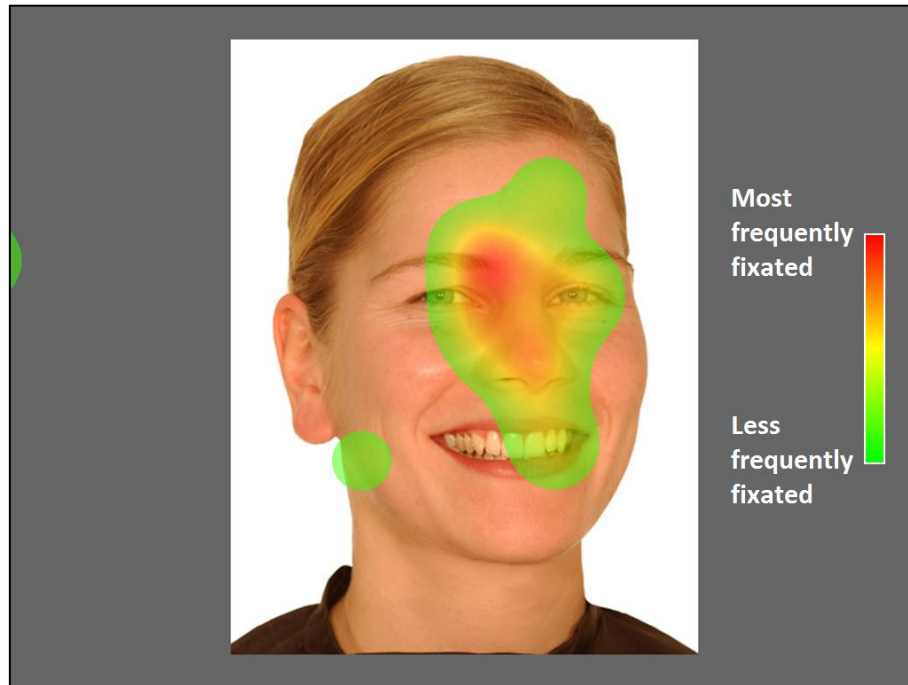
Figure 5. The same looking behavior as depicted in Figure 3 and 4 illustrated as a heatmap. The frequently fixated areas are painted in red whereas the less fixated areas are painted in green or have no color at all.

The most commonly measured looking behavior with corneal reflection eye trackers is a combination of fixations and saccades however most of these eye trackers can also record pupil size. Here, it is measured how large the pupil is when specific stimuli are presented and whether this changes when other stimuli are shown. It has to be noted that pupil size is also determined by environmental factors, such as ambient light, and is therefore less often used in eye tracking research (Poole & Ball, 2005).

Two Eye Tracking Applications: Passive vs. Active Gaze-Contingent Eye Tracking

Eye tracking can either be applied in a passive or an active gaze-contingent manner. In most eye tracking research the eye tracking method is applied in a passive manner. However, newer eye tracking techniques have made it easier to apply eye tracking in an active gaze-contingent manner. An overview of the main differences between passive and active gaze-contingent eye tracking is described in Figure 6.

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│       Eye Tracking      │
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Passive Eye Tracking

Measuring and recording of looking
behavior to investigate what is looked at

Looking behavior is coded online or offline

Active Gaze-Contingent Eye Tracking

Looking behavior is not only measured and
recorded but it is also used to change
something on the display screen

Looking behavior is coded online and
specific looking behavior is coupled to a
contingent change within the stimuli
presented on the display screen

Different gaze-contingent techniques:

• Direct gaze-contingent change
• Boundary
• Moving window

Figure 6. Schematic overview of passive and active gaze-contingent eye tracking.

In Figure 6 it is shown that *passive eye tracking* is the measuring and recording of looking behavior to investigate what is looked at. This passive looking behavior can be coded online or offline. Within some passive eye tracking research online coded looking behavior is used to automatize the experimental eye tracking procedure. An example is that a new stimulus will automatically appear on the display screen after an old stimulus is looked at for a predefined amount of time (criterion; i.e., 30 s). Only when the passive looking time criterion is reached, will the program automatically proceed and it is again measured how long this new stimulus is fixated.

In contrast to passive eye tracking, where looking behavior is only registered, *active gaze-contingent eye tracking* directly makes use of looking behavior in that a visual display changes contingent on where and when a subject's eyes move or fixate. Within active gaze-contingent eye tracking research looking behavior is coded online and specific looking behavior is directly coupled to a contingent change within the stimuli presented on the display screen (see Duchowski, Cournia, & Murphy, 2004; Jacob, 1990; Jacob & Karn, 2003, for

overviews). Therefore, in such active gaze-contingent eye tracking studies subjects are able to influence or control their visual environment with their looking behavior.

This influence or control over the visual environment within active gaze-contingent eye tracking can be applied in various ways, and therefore several different kinds of *active gaze-contingent eye tracking techniques* exist. Examples of such techniques are the direct gaze-contingent change technique, the boundary technique, and the moving window technique. In the *direct gaze-contingent change technique* looking behavior is used to directly manipulate the stimuli presented on the display screen. Here, a stimulus moves, freezes, or disappears when it is looked at (e.g., Deligianni, Senju, Gergely, & Csibra, 2011; Murata, 2006). The *boundary technique* is similar to the direct gaze-contingent change technique in that a stimulus is changed when a subject looks at a specific area of the display screen. However, within this technique the looking behavior does not directly manipulate the stimulus looked at but a different stimulus on the display screen. Therefore, when a subject's looking behavior crosses a specific boundary (which can be visible or invisible) something else on the display screen changes (e.g., Holmboe, Fearon, Csibra, Tucker, & Johnson, 2008; Rayner, 1975). The *moving window technique* (McConkie & Rayner, 1975; see Rayner 1998 for an overview) consists of a direct visual field around a fixation location that is displayed normal (window) and the surrounding part of the visual field that is altered (e.g., blurred). Within an experiment, where the moving window technique is used, subjects can move the normally displayed window contingent on where they look. An example of a face stimulus presented within an experiment in which the moving window technique is used is displayed in Figure 7. This subject fixates on the eye which is displayed normal whereas the rest of the face stimulus and the display screen are blurred.
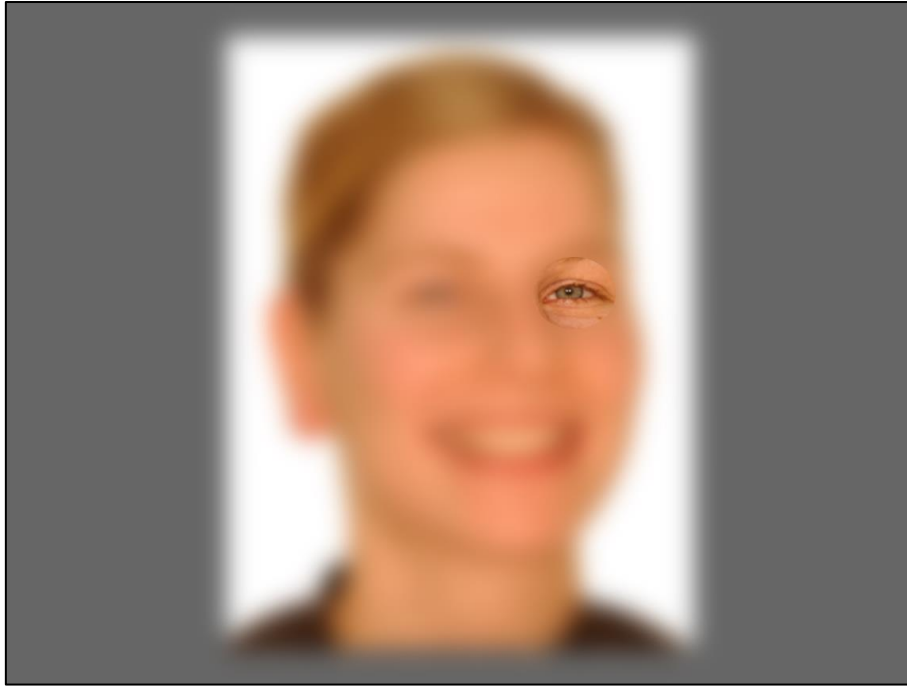
Figure 7. Example of a face stimulus presented within an experiment in which the moving window technique is used. The area around the fixation location (direct visual field) is displayed normal whereas the surrounding part of the visual field is altered.

Although all of these active gaze-contingent techniques function differently, they all cause a subject to be able to directly change, influence, or control the display screen with their looking behavior.

Summary

This chapter provided an historical and methodological review of eye tracking. Over the years, the eye tracking techniques used to measure looking behavior changed from observations made by human coders to fully automatic eye tracking systems. Nowadays, not only the direction of looking behavior but also the exact gaze location can be measured. Here, eye tracking measures like, for example, fixations and saccades provide information on what is looked at. Eye tracking can either be applied in a passive or active gaze-contingent manner. Within passive eye tracking research looking behavior is only measured and registered whereas within active gaze-contingent eye tracking research looking behavior is directly used to change, influence, or control the display screen.

Chapter 3

Eye Tracking: Psychological Research with Infants and Adults

In the previous chapter a historical and methodological review of eye tracking was provided, however, the usage of the eye tracking methodology within *psychological research* was not described. In the present chapter it is explained why psychologists use eye tracking as a research tool. Moreover, as this research tool is not only used within adult but also within infant research an overview of passive and active gaze-contingent looking behavior research within infant as well as adult populations is given.

Why do Psychologists use Eye Tracking as a Research Tool?

Looking behavior towards specific stimuli tells psychologists a lot about what is being processed in the mind of their subjects (Aslin, 2012; Holšánová, Andersson, Johansson, Holmqvist, & Strömqvist, 2010). Therefore, eye tracking is a very important *research tool* for psychologists. The rationale behind eye tracking is that we pay attention to where we look at (Duchowski, 2007). Although it is known that the relation between direction of gaze and attention is not always perfect (e.g., covert visual attention to peripheral visual stimuli or a blank stare), it is presumed that looking behavior can provide important information about the underlying cognitive processes such as *attention*, *learning*, and *memory* (e.g., Aslin & McMurray, 2004; Williams, 2013). Therefore, psychologists developed various *looking behavior tasks* to make inferences about such specific cognitive processes. However, which cognitive processes are measured depends on the looking behavior task administered.

Different looking behavior tasks were developed to measure cognitive processes such as attention, learning, and memory in both *infancy* (for overviews see Aslin, 2007; Aslin & McMurray, 2004; Gredebäck, Johnson, & von Hofsten, 2010; Oakes, 2012) and *adulthood* (for overviews see Liversedge, Gilchrist, & Everling, 2011; Rayner, 1998; Richardson & Spivey, 2008b). Such tasks are especially important in infancy research as studying cognitive processes within an infant population is difficult. Infants are still pre-verbal and have limited motor repertoires, however, looking behavior offers an opportunity to make inferences about infants' cognitive processes as they can control their eye movements comparatively early (e.g., Bronson, 1990; Johnson, Posner, & Rothbart, 1991). Although cognitive processes in adulthood can also be measured verbally or by other motor tasks, looking behavior tasks might provide additional information which cannot be measured in another way. Therefore, looking behavior tasks are important tools to measure cognitive processes over the whole lifespan.

The following paragraphs provide an overview of passive and active gaze-contingent looking behavior tasks that are frequently applied within infant and adult research. It is described how these tasks function and how specific looking behavior within these tasks relate to the cognitive processes which they are supposed to measure.

Passive Looking Behavior Tasks

Infant Research

Since the 1950's, psychologists use looking behavior to investigate infant cognition via a variety of passive looking behavior tasks. Examples of frequently used passive looking behavior tasks that are supposed to measure infants' attention, learning, and memory, are the visual preference task, the visual paired comparison task, the habituation-dishabituation task, and the visual expectation task.

The *visual preference task* developed by Fantz (1958, 1963), is one of the first passive looking behavior tasks used within infancy research. This task was developed to measure whether infant's have *spontaneous preferences* for some visual stimuli over other visual stimuli (e.g., Fantz, 1958). Within a visual preference task, different visual stimuli are presented and it is measured how long an infant looks at each stimulus. Longer looking times are thought to represent a higher visual interest or a preference for the longer looked at stimuli over the shorter looked at stimuli. Moreover, it is assumed that this preference for the longer looked at stimulus over the shorter looked at stimulus indicates that infants are able to discriminate between the presented stimuli (Fantz, 1963). In one of his studies, Fantz (1963) used this task and compared new born infants' looking times to visual patterns (e.g., black-and-white pattern of a schematic face and circles) and plain colors (e.g., yellow and red). The results showed that the infants looked longer to the visual patterns than to the plain colors. Therefore, this study demonstrated that newborn infants are already able to discriminate between visual patterns and plain colors.

This pioneering work with the visual preference task (Fantz, 1958, 1963) is the backbone of many other looking behavior tasks developed to measure a variety of cognitive processes in infancy including *discriminatory* and *recognition memory*. Two passive looking behavior tasks that are based on the visual preference task and that are used to measure infants' discriminatory and recognition memory are the *visual paired comparison* (*VPC*) and the habituation-dishabituation tasks (e.g., Hayne, 2004; Pascalis & de Haan, 2003; Rose, Feldman, & Jankowski, 2004). Within a typical VPC task, infants are initially familiarized with one or two simultaneously presented identical stimuli. These stimuli might be presented

only once or repeatedly as well as for preset periods of time or until the infant has accumulated a specific amount of time looking at it. After an infant is familiarized, a test phase is administered in which a novel and the familiar stimulus are simultaneously presented.

The *habituation-dishabituation task* is very similar to the VPC task. Within a typical habituation-dishabituation task, infants are initially familiarized with a repeatedly presented single stimulus. This familiarization period is also called the habituation phase (e.g., Pascalis & de Haan, 2003; Rose et al., 2004). The repeatedly presented stimulus is either presented in a fixed trial or an infant-controlled manner. Within fixed trial procedures the repeatedly presented stimulus is presented within trials that have a fixed duration. The duration of these trials are preset by the experimenter and infants are free to look or not to look at the stimuli presented during each trial. With the development of newer eye tracking techniques it became possible to design infant-controlled procedures. Within such infant-controlled procedures, the habituation phase ends when an infant's looking behavior has been reduced to some criterion. Here, an infant's looking behavior is used to automatize the habituation-dishabituation procedure (see also Chapter 2, page 19). For example, the habituation phase ends after an infant's looking time on three consequent trials is 50% of the looking time on the first three trials (Colombo, 1993; Colombo & Mitchell, 1990). When infants' looking time drops to the 50% criterion, infants are thought to be habituated and a dishabituation phase is administered. Within the dishabituation phase a single presented novel stimulus is followed by the single presented familiar stimulus or vice versa. Therefore, the main difference between the VPC and the habituation-dishabituation task is that within the VPC task the novel and familiar stimulus are simultaneously presented whereas within the habituation-dishabituation task the novel stimulus is presented alone (Pascalis & de Haan, 2003).

Within both the VPC and habituation-dishabituation tasks, the infants' looking time to each of the presented stimuli is assessed. An influential explanation of infant looking behavior during both tasks is provided by the comparator model (Sokolov, 1963) which directly links looking behavior to learning and memory (e.g., Colombo & Mitchell, 2009). According to this model infants construct a mental representation of the stimuli they encounter. The looking time to each stimulus is determined by the discrepancy between the memory representation and the stimulus presented (e.g., Hayne, 2004; Kavšek, 2004, 2013). Therefore, looking time to the stimulus during familiarization generally decreases as the mental representation becomes increasingly similar to the stimulus presented (Pascalis & de Haan, 2003). When an infant-controlled habituation-dishabituation procedure is used it might even be presumed that

all habituated infants are at the same level of stimulus encoding (e.g., Oakes, 2010) whereas this might not be presumed for infants tested in a VPC or habituation-dishabituation task in which the stimuli are presented for fixed amounts of time (fixed-trial procedures). In line with the comparator model (Sokolov, 1963) it is thought that the looking behavior measured during the test or dishabituation phase might indicate discriminatory recognition memory. When the memory representation is complete, infants are supposed to be able to discriminate between the novel and familiar stimulus, which is indicated by a longer looking time to the novel as opposed to the familiar stimulus (e.g., Hayne, 2004; Kavšek, 2004, 2013).

A considerable amount of research has demonstrated that both the VPC and habituation-dishabituation tasks can be used to investigate infants' discriminatory recognition memory (for overviews see, Pascalis & de Haan, 2003; Rose et al., 2004). Different VPC and habituation-dishabituation studies have shown that infants are able to discriminate between different stimuli when the test or dishabituation phase was administered directly after familiarization or habituation (e.g., Fantz, 1964). It has also been found that these tasks can be used to investigate infants' long-term memory by administering the test or dishabituation phase after a longer delay (e.g., Pascalis, de Haan, Nelson, & de Schonen, 1998). Moreover, these tasks have become a standard procedure for assessing a broad range of cognitive processes including categorization and object representation (e.g., Baillargeon, 1987; Hayne, 1996).

Another passive looking behavior task that is frequently used within infant research is the visual expectation task which is also called the *visual expectation paradigm* (*VExP*). This task is developed to investigate infants' visual *information processing* and *prospective memory* (Haith, Hazan, & Goodman, 1988; for an overview see Haith, Wentworth, & Canfield, 1993). During a VExP study, stimuli appear at different spatial locations within a repeated sequence. An example of a typically used sequence is a left-right alternating one. Thereby, stimuli are presented for 700 ms and the time interval between stimuli is 1000 ms (e.g., Haith et al., 1988; Haith & McCarty, 1990). This task investigates whether infants are able to form visual expectations of the spatial locations of the upcoming stimuli. Visual expectations are measured by very fast reactive looking behavior to a predictable stimulus location and by anticipatory looking behavior to the upcoming stimulus location that occur prior to the appearance of the stimulus. Different studies using the VExP have indicated that infants are able to form visual expectations, and therefore that young infants already possess prospective memory capacities. Evidence is derived from the fact that infants showed enhanced reaction times and more anticipatory looking behavior for predictable stimulus

locations as opposed to less predictable stimulus locations (for an overview see Canfield, Smith, Brezsnyak, & Snow, 1997; Haith et al., 1988).

Adult Research

Two examples of frequently used passive looking behavior tasks used within adult samples are the change detection and visual search task. Both tasks are thought to measure attention, learning, and memory.

The *change detection task* was developed to measure *short-term memory*. Within a change detection task, a change is made in a previously viewed scene during a short disruption. It is investigated whether the change is noticed (verbal measure) and what was looked at before and after the change occurred (Peterson & Beck, 2011). Here, it is examined whether the looking behavior on the changed region before and after the change appeared relates to subjects' change detection. Studies that have used such tasks have shown that longer looking times to regions that were later changed increased the probability of detecting a change (e.g., Henderson & Hollingworth, 1999; Hollingworth & Henderson, 2002). Furthermore, it was found that change detection related to higher looking times on the changed object (Hollingworth & Henderson, 2002). Consequently, change detection requires looking behavior (visual attention) to the object location before (memory) and after the change appeared (e.g., Peterson & Beck, 2011).

The *visual search task* is a passive looking behavior task that can be used to measure *long-term memory*. This task consists of a display screen on which a specific target and distractor stimuli are simultaneously presented. Within this display screen subjects have to search for a specific target stimulus. Looking behavior on the target and distractor stimuli is measured and it is thought that this looking behavior might relate to long-term memory performances. For instance, Williams, Henderson, and Zacks (2005) investigated whether the looking behavior during a visual search task influenced the remembering of the targets and distractors in a long-term memory task that was administered after ten minutes (verbal task). They found that the remembered targets were more frequently looked at than the targets that were not remembered. Moreover, it was found that category and color distractors were more frequently looked at and falsely remembered than unrelated distractors. This study demonstrated that with increasing looking time subjects show better retention performance.

Active Gaze-Contingent Looking Behavior Tasks

Infant Research

The use of active gaze-contingent looking behavior tasks to investigate cognitive processes in infancy is still scarce. Until now, the scattered studies that have used active gaze-contingent eye tracking tasks to measure infants' cognition have investigated infants' inhibitory functioning (Holmboe et al., 2008), orientation following (Deligianni et al., 2011), and attentional control (Wass, Porayska-Pomsta, & Johnson, 2011).

The first study that used an active gaze-contingent looking behavior task within an infant population was conducted by Holmboe et al. (2008). Within this study 9-month-old infants' *inhibitory functioning* was tested with the so called *Freeze-Frame task*. The Freeze-Frame task makes use of a boundary technique in that a central animated stimulus stops moving ('freezes') when an infant looks at a distractor stimulus that is presented in the periphery. The animated central stimulus was either a new and interesting animation that changed every 2 s (interesting trials) or the same uninteresting rotating orange star (boring trials). During the experiment boring and interesting trials were altered and the distractor stimulus (a white square) was randomly presented at the left or right side of the display screen. In this study infants' looking behavior on the distractor stimuli is measured. Within this task, a general decrease in looking behavior on the distractors in the interesting as well as the uninteresting trials is supposed to measure general inhibitory learning. Selective inhibition is thought to be measured by an initial difference in looking behavior on the distractor stimuli within the interesting and the uninteresting trials. Furthermore, a greater decrease in looking behavior on the distractor stimulus in the interesting trials than in the uninteresting trials is assumed to measure selective inhibitory learning. The results of this study showed that infants' initial level of distractibility was modulated by the attractiveness of the central animated stimulus. In the beginning of the experiment infants looked less to the distractor stimulus in the boring than in the interesting trials. However, the decrease in looking behavior on the distractor stimulus over trials was not influenced by trial type. Therefore, this study shows that infants learn to inhibit their looking behavior towards the distractor stimulus in a general non selective way. Moreover, follow up analysis showed that inhibitory functioning measured in the Freeze Frame task related to measures of frontal cortex functioning in other tasks. Therefore, this study provides evidence that the Freeze Frame task can be used to investigate inhibitory functioning as well as frontal cortex functioning at a very early age.

Deligianni et al. (2011) used an active gaze-contingent looking behavior task to investigate whether 8-month-old infants follow the turning of a central object toward a target stimulus (*orientation following*). It has been shown that young infants follow the gaze of an interactive human partner (e.g., D'Entremont, Hains, & Muir, 1997; Senju & Csibra, 2008). However, in the study of Deligianni et al. (2011) it was investigated whether infants also follow the turning of a central object that moves gaze-contingent. In this study infants were either tested in a gaze-contingent or yoked control condition. The gaze-contingent condition consisted of a direct gaze-contingent change technique in that the central object moved when infants looked at it. The moving of the object ended when the object had turned to a target stimulus which was one of two stimuli placed at the bottom left or bottom right of the stimulus presentation screen. Infants in the yoked control condition saw a playback of a video of an infant in the gaze-contingent condition. It was assessed how often the infants looked to the target stimulus in both conditions. Results of this study showed that infants in the gaze-contingent condition showed more saccades towards and higher looking times on the target stimulus as infants in the control condition. These results indicate that infants in the gaze-contingent condition followed the turning of the object toward the target stimulus whereas infants in the yoked control condition did not. The authors suggest that the infants in the gaze-contingent condition might have followed the turning of the contingent object as they interpreted the object as an agent with communicative intentions. This study showed that contingency can function as an ostensive cue or communicative signal which might direct infants' looking behavior.

In the study of Wass et al. (2011), different active gaze-contingent looking behavior tasks were used to train 11-month-old infants' *attentional control*. In this study four different active gaze-contingent looking behavior tasks were used as training, and therefore the main focus was not on infants' looking behavior during the active gaze-contingent tasks. The experiment consisted of five laboratory visits that took place over a time frame of 15 days. Pre- and posttests that measured attentional control (e.g., cognitive control, visual attention, and working memory) were administered at the first and last visit, respectively. Between these visits infants were either trained with active gaze-contingent tasks targeting attentional control (gaze-contingent condition) or viewed infant-appropriate animations or television clips (control condition). Infants in the gaze-contingent group were trained with four different active gaze-contingent tasks, i.e., the butterfly, stars, elephant, and windows task, which were rotated each experimental session. These active gaze-contingent tasks made use of direct gaze-contingent changes but also of invisible boundaries techniques. The butterfly task

consisted of a butterfly that flew across the display screen when an infant looked at it (direct gaze-contingent change technique). Distractor stimuli that moved in the opposite direction were also presented. Every time an infant looked at a distractor the butterfly stopped flying and the distractors disappeared (direct gaze-contingent change technique). However, when an infant looked at the butterfly again, it recommenced flying and the distractors reappeared. The stars task is a visual search task in which infants had to search for a target that was simultaneous presented with eight smaller distractor stimuli. The targets changed from trial to trial and in total five different targets (all cartoon characters presented within a star from) were used. Infants received an animation as a reward when they looked at the target (boundary technique) within the first 3000 ms of a trial. Another visual search task that was used was the elephant task. In the elephant task, infants had to search for a target (an elephant) that was presented with one or more distractor stimuli of the same size. When an infant looked at the target an animation was presented as a reward (boundary technique). During the first 28 trials the same target was used and afterwards the target changed (e.g., from elephant into chicken). The windows task consisted of a target animal in a window that disappeared behind one of several other windows after an infant looked at it (direct gaze-contingent change technique). When the target animal had disappeared, all the windows were covered with curtains and a flower appeared elsewhere on the screen. This flower moved when an infant looked at it (direct gaze-contingent change technique) and was only presented for a particular amount of time. After the flower disappeared the windows, which were shown during the beginning of the experimental session, reappeared. When an infant looked back to the window where the target animal disappeared an animation was presented as a reward (boundary technique). These four active gaze-contingent tasks were designed to target aspects of attentional control like visual search (stars and elephant task), inhibitory functioning (stars and elephant task), task switching (elephant task), visuospatial working memory (windows task), selective attention (butterfly task), and interference resolution (butterfly task). The attentional control measures on the pre- and posttest of infants in the gaze-contingent and control condition were investigated. Compared to the control condition, it was found that infants in the gaze-contingent condition showed improvements on the attentional control posttest measures, namely sustained attention and cognitive control. Therefore, this study showed that active gaze-contingent tasks can be used to train aspects of attentional control in infancy.

Adult Research

Active gaze-contingent looking behavior tasks have also been applied to investigate cognitive processes in adulthood. They are, for example, used to measure parafoveal semantic processing (Hyönä & Häikiö, 2005) or visual span (e.g., McConkie & Rayner, 1975; Reingold, Charness, Pomplun, & Stampe, 2001).

In their study Hyönä and Häikiö (2005) used an active gaze-contingent looking behavior task to investigate *parafoveal semantic processing* (i.e., an access to the word meaning is achieved) in reading. In this study the boundary technique was used in that a change on the display screen occurred after a persons' fixation crossed an invisible boundary which was a location in text. Just before a subject looked at a parafoveal preview word it changed into a target word. Therefore, subjects were not able to inspect the paravofeal preview word foveally. In this study three types of parafoveal preview conditions were contrasted: an emotional word, a neutral word, and an identical word (where no change is made) condition. The target word was the same over all three conditions. In this study it was investigated whether the looking behavior on the target words differed across conditions. The authors assumed that subjects looking time to the target words coupled to emotional parafoveal preview words would be the highest. As it is thought that emotional words are more readily obtained from the parafoveal (e.g., Calvo & Lang, 2005), they should be looked at earlier compared to the other parafoveal preview words used. However, the results of this study showed that there is no difference in looking behavior on the target word over the three conditions. This result indicates that only the words that are looked at during reading are semantically processed whereas the words that are presented in the parafoveal view are not.

The *size of visual span* within reading (McConkie & Rayner, 1975) but also within other domains (e.g., Reingold et al., 2001) can be investigated with moving window tasks. Moving window tasks make use of the moving window technique, in that the direct visual field around a fixation location is displayed normally whereas the rest of the visual field is altered. To measure a subject's visual span, the size of the normally displayed window is varied over successive trials. For example, Reingold et al. (2001) used a moving window task to compare the visual span of expert chess players with that of non-expert chess players. Previous research has demonstrated that expert chess players might have an advantage in early perceptual organization and internal representation of chess positions (e.g., Chase & Simon, 1973). Therefore, the authors hypothesized that expert chess players compared to non-expert chess players might possess looking behavior advantages when processing chess

related chessboards. They expected that expert chess players had a greater visual span than non-expert chess players when processing chess related chessboards as they would make greater use of parafoveal processing to extract information from a larger proportion of the chessboard. The results of this study were in line with this hypothesis. Reingold et al. (2001) demonstrated that expert chess players had larger visual spans than non-expert chess players while processing structured chess positions, whereas there was no difference in visual span while processing random chess positions. Therefore, this study indicates that expertise within a specific domain relates to visual span within that domain.

Within adult samples active gaze-contingent looking behavior tasks are not only applied to investigate cognitive processes such as parafoveal semantic processing and visual span, however, they are also used to give subjects *active control* over their visual environment. In such studies active gaze-contingent looking behavior tasks are applied to investigate whether subjects are able to use their looking behavior in order to influence or control the visual environment (e.g., Frey, White, & Hutchinson, 1990; Jacob, 1990; Murata, 2006; Sibert & Jacob, 2000; Ware & Mikaelian, 1987). This testing whether subjects are able to use their looking behavior within active gaze-contingent tasks in order to influence or control the visual environment is part of a larger research area called human computer interaction (HCI).

Many of the active gaze-contingent looking behavior tasks that are applied in such HCI studies make use of direct gaze-contingent change techniques. In such studies it is often examined whether subjects are able to move a computer cursor with their looking behavior. Different HCI studies have shown that instructed adult subjects (they were told how it works) are able to move a computer cursor by looking at it (e.g., Frey et al., 1990; Jacob, 1990; Murata, 2006; Sibert & Jacob, 2000; Ware & Mikaelian, 1987). Moreover, when comparing target selection with looking behavior within an active gaze-contingent looking behavior task to target selection with more conventional systems (e.g., computer mouse, button press), an advantage for target selection within an active gaze-contingent looking behavior task was found (Murata, 2006; Sibert & Jacob, 2000; Ware & Mikaelian, 1987). Sibert and Jacob (2000), for instance, showed that subjects were faster at selecting targets with their looking behavior within an active gaze-contingent task than at selecting targets with computer mouse selection. These studies revealed that instructed adults are able to use their looking behavior to control a display screen within active gaze-contingent looking behavior tasks in which a computer cursor can be moved with looking behavior. Moreover, such tasks in which a computer cursor is moved with looking behavior can be used for typing. Therefore, such

active gaze-contingent looking behavior tasks might provide an opportunity to give people with various types of locked-in syndrome (for an overview of this syndrome see Ramos-Murguialday et al., 2011) and paralysis a way to interact and communicate with others (Mollenbach, Stefansson, & Hansen, 2008).

Summary

This chapter showed that eye tracking is an important tool in psychological research as looking behavior within specific looking behavior tasks can be used to make inferences about cognitive processes such as attention, learning, and memory. Therefore, different passive and active gaze-contingent looking behavior tasks were developed to measure cognitive processes in infancy as well as adulthood. Additionally, active gaze-contingent looking behavior tasks are also applied to give adult subjects active control over their visual environment.

Chapter 4

A New Active Gaze-Contingent Looking Behavior Task:
Giving Infants and Younger as well as Older Adults Control over their Visual
Environment with Looking Behavior

The research reviewed in the previous chapter showed that passive and active gaze-contingent looking behavior tasks are applied to investigate cognitive processes such as attention, learning, and memory within infant and adult populations. Next to studying cognitive processes, active gaze-contingent looking behavior tasks also allow subjects to actively control their visual environment with looking behavior. So far, however, such active gaze-contingent looking behavior tasks are only seldom used for active visual environment control.

As described in Chapter 3, such active gaze-contingent looking behavior tasks are already used to give adult subjects control over their visual environment. In most of these studies adults had to move a computer cursor with their looking behavior (e.g., Frey et al., 1990; Jacob, 1990; Murata, 2006; Sibert & Jacob, 2000; Ware & Mikaelian, 1987). However, such tasks have not been used to give preverbal infants, who have limited motor repertoires, the opportunity to actively control their visual environment. Thus far, infant studies with such tasks have focused on investigating cognitive processes such as inhibitory functioning (Holmboe et al., 2008), orientation following (Deligianni et al., 2011), and attentional control (Wass et al., 2011). Nevertheless, in these studies it was not examined whether infants could use such a task to actively control their visual environment. Hence, what is still missing in infancy research is an empirical test of whether infants are able to learn to control their visual environment within such an active gaze-contingent looking behavior task.

Moreover, an opportunity that active gaze-contingent looking behavior tasks provide is the ability to examine infants as well as adults within the same actively controlled environment. Therefore, such tasks make it possible to conduct a *lifespan examination* on how infants as well as adults learn to control their visual environment with looking behavior.

The present dissertation consists of such a lifespan examination on how infants and younger as well as older adults learn to control their visual environment with looking behavior. In order to conduct this lifespan examination a newly developed lifespan oriented active gaze-contingent looking behavior task is introduced. This newly developed task is called the *gaze-contingent learning task* (*GCLT*) as within this task subjects learn to control their visual environment with looking behavior by acquiring a gaze-contingent association

between their looking behavior and a visual effect. In essence, this learning of a gaze-contingent association is a form of *operant conditioning learning*, i.e., a process in which subjects learn to perform a specific behavior that results in specific effects (e.g., Gray, 2002a; Mazur, 2004; Skinner, 1938; Sutton & Barto, 1998; Thorndike, 1911). Because a large amount of research has shown that adults as well as infants are able to learn to perform such behavior (e.g., Domjan, 2003; Gray, 2002a; Mazur, 2004; Rovee-Collier & Gekoski, 1979; Rovee-Collier, Hayne, & Colombo, 2001; Rovee-Collier & Barr, 2010) it is thought that the GCLT is a lifespan oriented task.

The two main versions of the GCLT used in this dissertation are the one disc GCLT and the two discs GCLT. An example of the *one disc GCLT* is depicted in Figure 8. Methodologically, the one disc GCLT uses a boundary technique in that subjects have to look at the disc at the right side of the display screen in order to trigger a new stimulus that appears at the left side of the display screen. In the one disc GCLT the triggered stimulus disappears after a prefixed period of time. However, in case a subject looks at the disc again a new stimulus will appear.
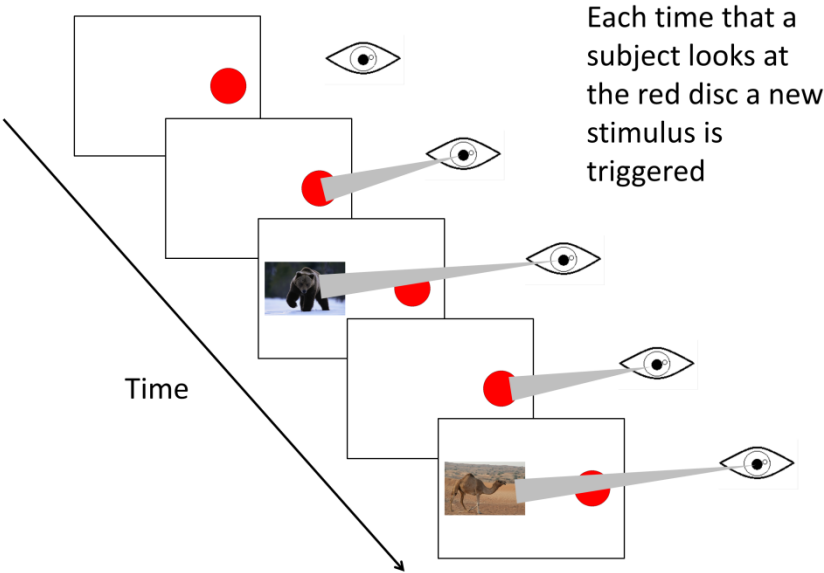
Figure 8. Example of the one disc GCLT.

An example of the *two discs GCLT* is depicted in Figure 9. The two discs GCLT differs from the one disc GCLT in that not one but two discs are presented. These discs are presented at the left and right side of the display screen. Within the two discs GCLT only one of the two red discs (within one session only left or right) has the function of triggering a new stimulus (functioning disc) that is presented in the middle of the display screen. When a subject looks at this functioning disc a stimulus is triggered whereas looking at the other disc (non-functioning disc) will not produce any effect. In the two discs GCLT the triggered stimulus does not disappear at once but slowly disappears within a prefixed period of time. However, in the case a subject looks at the functioning disc again a new stimulus will appear.
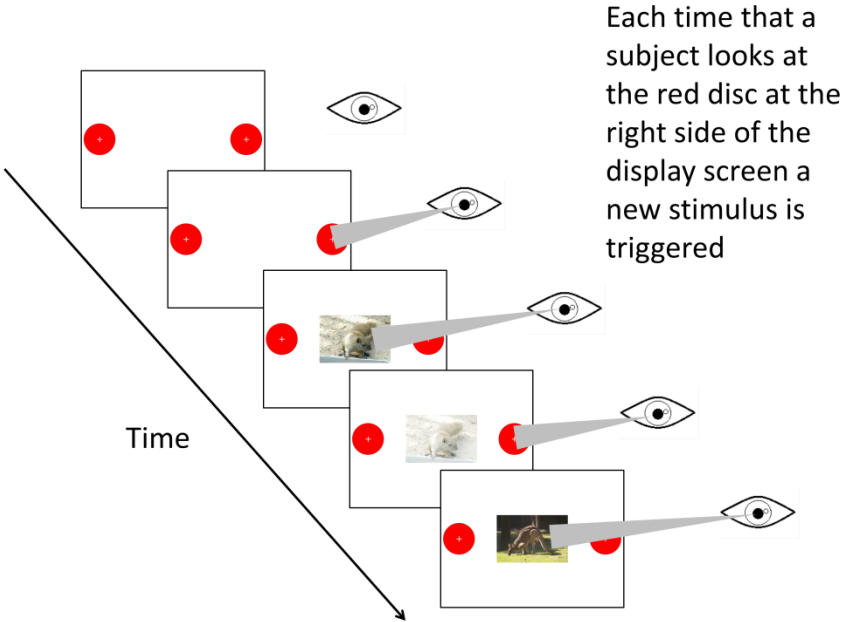
Figure 9. Example of the two discs GCLT.

Within the two discs GCLT, subjects are only able to acquire the gaze-contingent association when they learn to differentiate between the functioning and non-functioning disc. Therefore, *discrimination learning*, i.e., learning to respond differently to various stimuli (e.g., Gray, 2002a), also plays a role while acquiring the gaze-contingent association within the two discs GCLT.

Within this dissertation both versions of the GCLT are used to examine, over the lifespan, how infants and younger as well as older adults learn to control their visual environment with looking behavior. Therefore, the primary focus of this dissertation is

whether subjects of different ages learn gaze-contingent associations within GCLT set-ups. To investigate this question different experiments with variations of the one disc and two discs GCLT with infants and younger as well as older adults are conducted. However, before the various experiments are separately discussed the GCLT is theoretically integrated in the existing research literature. As operant conditioning learning is the main learning mechanism involved in learning the gaze-contingent association within the GCLT a review on operant conditioning learning in infancy and adulthood is provided.

Operant Conditioning Learning in Infancy and Adulthood

Operant conditioning learning is a learning mechanism that is used over the whole lifespan as is shown by the fact that adults as well as infants are able to learn to perform behavior that result in effects (e.g., Domjan, 2003; Gray, 2002a; Mazur, 2004; Rovee-Collier & Gekoski, 1979; Rovee-Collier et al., 2001; Rovee-Collier & Barr, 2010). However, developmental differences cause that operant conditioning learning is differently assessed in infancy and adulthood. Moreover, it could be that there are developmental differences in the underlying learning processes that contribute to and in the perceptual processes that are involved during operant conditioning learning.

Assessing Operant Conditioning Learning in Infancy and Adulthood

Developmental differences in assessing operant conditioning learning exist in that operant conditioning learning is differently assessed in infancy and adulthood. Whereas adults' operant conditioning learning is assessed *verbally*, infants' operant conditioning learning can only be assessed *behaviorally* by measuring *response behavior* (i.e., the behavior that produces the effect) and *expectancies* (i.e., anticipations to the effect that will occur).

Behavioral indicators of infants' operant conditioning learning are assessed in operant conditioning tasks that are specifically developed for infants (for overviews see Rovee-Collier & Gekoski; 1979; Rovee-Collier et al., 2001; Rovee-Collier & Barr, 2010). Such infant appropriate operant conditioning tasks make use of response behaviors that infants can already perform like, for example, *sucking* (e.g., Eimas, Siqueland, Jusczyk, & Vigorito, 1971; Siqueland & Delucia, 1969), *head turning* (e.g., Siqueland, 1968; Siqueland & Lipsitt, 1966; Werker, Polka, & Pegg, 1997; Werker et al., 1998), *kicking* (Sullivan, Rovee-Collier, & Tynes, 1979; Rovee & Rovee, 1969; Rovee-Collier, Sullivan, Enright, Lucas, & Fagan, 1980), and *pressing a button* (e.g., Hartshorn & Rovee-Collier, 1997; Hartshorn et al., 1998).

Sucking behavior is used as response behavior within *high amplitude-sucking tasks*. In such tasks it is investigated whether young infants (under 6-months of age) learn to perform

specific sucking behavior that produces visual (Siqueland & DeLucia, 1969) or auditory (e.g., DeCasper & Fifer, 1980; Eimas et al., 1971; Floccia, Christophe, & Bertoncini, 1997) effects. Within *conditioned head-turn tasks*, head turning is used as response behavior. In such tasks it is examined whether young infants learn to perform specific head-turns that result in food (Siqueland & Lipsitt, 1966), non-nutritive nipple sucking (Siqueland, 1968) and visual or auditory effects (Werker et al., 1997, 1998). Another response behavior that is used in specific operant conditioning tasks developed for young infants is kicking. Such kicking is used as response behavior within *mobile conjugate reinforcement tasks* (for an overview of the standardized procedure see, Sullivan et al., 1979; Rovee-Collier et al., 1980). Within a typical mobile conjugate reinforcement task, an infant's leg is connected to an overhead mobile via a ribbon which causes the mobile to move when the infant kicks' his or her leg (for an example see Figure 10). In such tasks infant's kicking causes the mobile to move in a conjugate manner, i.e., stronger kicking produces a corresponding intensity in mobile moving (Rovee & Rovee, 1969).

Figure 10. Example of a 6-month-old infant tested with the mobile conjugate task in a study of the Developmental Psychology Lab of the Goethe-University Frankfurt am Main.

A response behavior that cannot be performed by very young infants but that is used in specific operant conditioning tasks developed for older infants (between 6- and 24-months of age) is pressing a button. Pressing a button is used as response behavior within *train tasks*. In

such tasks it is assessed whether older infants learn to press a button which causes the movement of a miniature train that runs on a circular track (for an overview see, Hartshorn & Rovee-Collier, 1997).

When testing infants in such infant appropriate operant conditioning tasks it is thought that an increase in response behavior within an experimental session and expectancies to the upcoming effect indicate operant conditioning learning. However, when an increase in response behavior within an experimental session is used as an indicator of operant conditioning learning, what kind of learning this increase in response behavior reflects is debatable. Traditionally (e.g., Thorndike, 1911; Skinner, 1938), it is thought that such an increase in response behavior indicates that an association between *stimulus* (*S*) and *response* (*R*) is learned (*S-R association learning*). An important implication of this *traditional account* is that S-R association learning can be viewed as a *mechanistic process* in which a *simple binary association* is learned (e.g., Gray, 2002a; Kirsch, Lynn, Vigorito, & Miller, 2004). However, when such a simple binary association between stimulus and response is learned subjects do not necessarily learn consciously that an effect is produced by their own behavior.

In contrast to this traditional account, *contemporary accounts* (e.g., Rescorla, 1991) suggest that an increase in response behavior within an operant conditioning task might indicate more than S-R association learning. They propose that such an increase in response behavior could also indicate that an association between response and effect or *outcome* (*O*) is learned (*R-O association learning*). Here, it is thought that expectancies about an effect are formed and that subjects might become aware that an effect is produced by their own behavior. However, two different contemporary perspectives exist. On the one hand, there is the *contemporary mechanistic perspective* that proposes that R-O association learning reflects the activation of simple binary associations (mechanistic process) that only produce a low-level form of expectancy. From this perspective, higher cognitive processes are only marginally involved, if involved at all, and subjects do not necessarily learn consciously that an effect was produced by their own behavior. On the other hand, there is the *cognitive perspective* that proposes that R-O association learning indicates the use of *higher cognitive processes* like, for example, memory that produces expectancies and might also produce *conscious awareness of the association between own behavior and effect* (Kirsch et al., 2004). Hence, these two contemporary perspectives agree that an increase in response behavior within an operant conditioning task indicates R-O association learning. However, they differ on whether this R-O association learning is mediated by mechanistic or by higher cognitive processes and on the likelihood that subjects might have learned that an effect was produced

by their own behavior. When this learning is mediated by a mechanistic process it could be *unconscious learning* whereas higher cognitive processes may cause *conscious learning*.

This debate, on what kind of learning an increase in response behavior within an experimental session of an operant conditioning task indicates, shows that such an increase might indicate S-R or R-O association learning. Whereas S-R and R-O association learning can both be explained by a mechanistic process, R-O association learning can also be explained by the use of higher cognitive processes. Moreover, when an R-O association is learned and higher cognitive processes have played a role during this learning, it might be suggested that subjects consciously learned that an effect was produced by their own behavior. Thus, it is important to investigate whether an increase in response behavior within an experimental session of an operant conditioning task indicates S-R or R-O association learning, as R-O association learning provide evidence that higher cognitive processes could have been used, and therefore that subjects might have consciously learned that an effect was produced by their own behavior.

In order to find out whether an increase in infants' response behavior measured within an operant conditioning task reflects S-R or R-O association learning, comparisons of infants' response behavior measured within *contingent conditions* and infants' *spontaneous behavior* measured in *non-contingent control conditions* are made. When infants in a non-contingent control condition do not perform the specific behavior, which is used as response behavior within the contingent condition, as spontaneous behavior to the same stimulus this suggests that operant conditioning learning is not due to S-R association learning. An example of a study in which such a comparison is made is from Rovee and Rovee (1969). In this study 10-week-old infants were either tested in a contingent or control condition of a mobile conjugate reinforcement task. Infants in the contingent condition could move a mobile by kicking their leg whereas infants in the control condition could not. The mobile of the infants in the control condition was also moved, however, this movement was not activated by the infant but by an experimenter. The results of this study showed that the kicking rate of the infants in the control condition did not change over the experimental session. However, the infants in the contingent condition learned to move the mobile by kicking as their kicking rate tripled within 6 min of conditioning. This comparison demonstrates that infants increase in response behavior in the contingent condition does not reflect S-R association learning as it is shown that infants do not show this behavior as spontaneous behavior to the same stimulus in the non-contingent control condition. Therefore, this increase in response behavior for the infants in the contingent condition might indicate R-O association learning.

Additional evidence that infants' response behavior measured within operant conditioning tasks reflects more than S-R associations learning comes from studies in which infants have to learn to *discriminate* when a specific behavior causes an effect and when not. For example, in an experiment with the conditioned head-turn task, Siqueland and Lipsitt (1966) investigated whether newborn infants could discriminate when a head-turn caused an effect and when not. In this experiment, a head-turn in the presence of an auditory cue resulted in the administration of a dextrose-water solution (contingent cue) whereas head-turns in the presence of another auditory cue did not produce an effect (non-contingent cue). To control for spontaneous head-turn behavior to one of the two auditory cues the association between auditory cue and effect were reversed halfway the experiment. The results demonstrated that during both parts of the experiment infants showed more head-turn behavior when a contingent cue was presented than when the non-contingent cue was presented. This study showed that infants are able to discriminate when a head-turn will produce an effect and when not. Moreover, these findings indicate that infants learned more than an S-R association as they only performed the specific behavior, which is used as response behavior, when a contingent cue was presented whereas they did not show this specific behavior as spontaneous behavior to the same cue when it was non-contingent. Such discriminatory behavior shows that an increase in infants' response behavior is not due to S-R association learning, however, that this learning might indicate R-O association learning.

A behavioral indicator that might provide more direct information on infants' R-O association learning within operant conditioning tasks is expectancies. Infants' expectancies were already investigated by Haith et al. (1988) within the VExP. As described in Chapter 3 (see pages 24-25), studies with the VExP showed that infants are able to form visual expectations of spatial locations of upcoming stimuli that are passively presented at different spatial locations within a repeated sequence. However, such expectancies can also be investigated within operant conditioning tasks in which infants actively control when an effect is produced. When infants show such expectancies to self-generated effects this provides evidence that they are able to learn R-O associations. An initial study that investigated infants' expectations within an operant conditioning task was performed by Kenward (2010). Within this study 10-month-olds infants had to press a button in order to start a video (contingent condition). Besides this contingent condition, two yoked control conditions in which infants saw a playback of a video of an infant in the contingent condition were tested. In one of the yoked control conditions an auditory effect was delivered after pushing the button and in the other condition no effect was delivered at all. Kenward (2010) investigated

whether infants in the contingent condition already looked at the reward location before the video appeared. Results of this study demonstrated that only infants in the contingent condition fixated the reward location before the video appeared whereas infants in the other two conditions did not. The infants in the yoked control condition did not show anticipatory looking behavior when a video started however they reacted to this video by looking at it after it started. These findings demonstrate R-O association learning for the infants in the contingent condition as it is shown that they formed expectations for the effect that occurs after performing response behavior. Moreover, the results of the infants in the control conditions showed that such expectancies are not formed during spontaneous looking behavior on the videos which additionally indicates that the learning in the contingent condition is not due to S-R association learning but must be ascribed to R-O association learning.

In brief, behavioral indicators like, response behavior and expectancies, are used to investigate infants' operant conditioning learning. Both of these behavioral indicators are used to show that infants' operant conditioning learning does not merely reflect S-R association learning but must be ascribed to R-O association learning. This behaviorally assessed R-O association learning might reflect a mechanistic process or the use of higher cognitive processes. When a mechanistic process is responsible for this learning, infants do not necessarily learn that an effect is produced by their own behavior, however, when higher cognitive processes are involved infants might have learned that an effect is produced by their own behavior. Therefore, behavioral indicators of operant conditioning learning can show that an R-O association is learned, nevertheless, it is unknown whether this learning indicates conscious or unconscious learning.

In contrast to infants' behaviorally assessed operant conditioning learning, adults' operant conditioning learning is assessed verbally by asking subjects whether they learned that there is an association between performing specific behavior and an effect. For example, in a task in which subjects have to find out whether the pressing of a computer key results in the illumination of a stimulus it is assessed whether subjects are able to verbally express that there is an association between their own pressing behavior and an effect or whether subjects are not able to verbally express this R-O association (e.g., Shanks & Dickinson, 1991). Hence, such a verbal indicator of operant conditioning learning directly shows whether subjects consciously learned that there is an R-O association between their own response behavior and an effect. Moreover, as it is thought that higher cognitive processes can produce conscious awareness of the association between own behavior and effect (Kirsch et al., 2004), it is

reasonable to assume that verbally assessed R-O association learning directly indicates that higher cognitive processes played a role during operant conditioning learning.

Behavioral indicators of operant conditioning learning, like response behavior and expectancies, are not so often measured when testing participants that can verbally express themselves. However, when such behavioral measures are additionally assessed it is often demonstrated that response behavior positively correlates to verbally expressed R-O association learning. Thus, it is found that subjects who can verbally express the association between their own behavior and an effect, also show a higher amount of response behavior than subjects who cannot verbally express the association between their own behavior and an effect (Kirsch et al., 2004). This finding shows that an increase in response behavior could indicate that subjects learned that an effect was produced by their own behavior. However, it has to be kept in mind that behavioral indicators are indirect measures of R-O association learning and that the only measure that provides certain evidence that subjects learned that an effect was produced by their own behavior is their verbal expression of the association.

To summarize, developmental differences cause that operant conditioning learning is differently assessed in infancy and adulthood. Infants' operant conditioning learning is assessed by behavior indicators like, response behavior and expectancies, whereas adults' operant conditioning learning is verbally assessed. Behavioral measures of operant conditioning learning might indicate R-O association learning. However, it remains unclear if this behaviorally assessed R-O association learning reflects a mechanistic process that causes infants to perform response behavior and to form low level expectancies but in which they do not learn that an effect is produced by their own behavior or if this learning reflects the use of higher cognitive processes in which infants might have learned that an effect is produced by their own behavior. On the contrary, verbal measures of operant conditioning learning directly show whether adults consciously learned the R-O association between their own behavior and effect. Moreover, such conscious learning implies that higher cognitive processes played a role during operant conditioning learning.

Developmental Differences in the Underlying Learning Processes that Contribute to Operant Conditioning Learning

There are not only developmental differences in how operant conditioning learning is assessed in infancy and adulthood, however, it might also be that there are developmental differences in the underlying *learning processes* that contribute to operant conditioning learning. In the previous paragraph, it was discussed that operant conditioning learning can be

explained by a mechanistic process or by the use of higher cognitive processes. In the previous paragraph it was suggested that a mechanistic process might cause subjects to perform response behavior and to form expectancies (unconscious learning), however, that higher cognitive processes could be necessary in order for them to become consciously aware that an effect is produced by their own behavior and to verbally express the R-O association that had to be learned.

It is important to note that both, a mechanistic process and the use of higher cognitive processes, are not mutually exclusive (e.g., Kirsch et al., 2004), and therefore that it is thought that both processes contribute to operant conditioning learning. Moreover such a *dual-process theory*[1] might suggest that the process that is mainly involved during operant conditioning learning varies over different stages of lifespan development.

For infants it can be speculated that the role that higher cognitive processes play during operant condition learning is relatively small as infants' cognitive abilities are still developing (e.g., Kenward, 2010). According to this reasoning, a mechanistic process might be very important during infants' operant conditioning learning whereas higher cognitive processes could play a minor role.

For adults it can be speculated that the role that higher cognitive processes play during operant conditioning learning is relatively large as adults' cognitive abilities are already matured. However, as it is thought that cognitive abilities decline from younger to older adulthood (e.g., Salthouse, 2004; 2009) it can be suggested that higher cognitive processes might play a smaller role during older adults' operant conditioning learning than during younger adults' operant conditioning learning.

When describing the role that higher cognitive processes play during operant conditioning learning in younger and older adulthood it is important to distinguish between two types of cognitive abilities. These two types of cognitive abilities are *mechanics* and *pragmatics*. Whereas pragmatics, i.e., knowledge acquired through education and cultural experiences, keep accumulating up to an age of about 60-70 years, mechanics, i.e., information processing and reasoning components necessary for novel problem solving, peak around 20-30 years of age and then constantly decline (e.g., Baltes, 1987; Birney & Sternberg, 2006; Cattell, 1971; Horn & Cattell, 1967). This subdivision of cognitive abilities in

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[1] These mechanistic and higher cognitive processes that may contribute to operant conditioning learning can be compared to a nonconscious implicit learning system and a conscious explicit learning system, respectively. These two learning processes are defined within dual-process theories of learning and memory (for an overview of dual-processing theories see Frankish & Evans, 2009).

mechanics and pragmatics shows that some higher cognitive processes which are part of mechanics might play a large role during operant conditioning learning in younger adulthood whereas other cognitive abilities which are part of pragmatics might play a large role during operant conditioning learning in older adulthood.

In short, as developmental differences in cognitive abilities between infants, younger, and older adults exist, it can be argued that the process that is mainly involved during operant conditioning learning varies over different stages of lifespan development. Whereas a mechanistic process might be important during operant conditioning learning in infancy, higher cognitive processes may be more important during operant conditioning learning in adulthood. However, it has to be kept in mind that higher cognitive processes which are part of pragmatics might be more important during operant conditioning learning in older adulthood whereas higher cognitive processes which are part of mechanics might be less important during operant conditioning learning in this period of life.

Developmental Differences in Perceptual Processes Involved during Operant Conditioning Learning

There might be developmental differences in the underlying learning processes that contribute to operant conditioning learning. However, it can also be suggested that there are developmental differences in the *perceptual processes* that are involved during operant conditioning learning.

Sensory information can be processed in a bottom-up and top-down manner. *Bottom-up processing* is the processing of *situational information* whereas *top-down processing* makes use of *prior knowledge* to interpret sensory information (Gray, 2002b). For operant conditioning learning it can be suggested that both, bottom-up and top-down, processes are involved, and therefore it is thought that situational information as well as prior knowledge influence operant conditioning learning (e.g., Alloy & Tabachnik, 1984)[2].

Examples of situational information that influence operant conditioning learning are *contingency* and *contiguity* (Elsner & Hommel, 2004; Hume, 1739/1969; Young, 1995). Contingency is the consistent co-occurrence of response behavior and effect. Hume (1739/1969) puts forward that an association between response behavior and effect is better learned when response behavior and effect reliably and consistently co-occur. Contiguity is the temporal proximity (latency time) between response behavior and effect. Typically, it is

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[2] This idea is also incorporated in the Bayesian Learning Theory. For an example of this theory see Gopnik and Tenenbaum (2007).

found that operant conditioning learning improves when the latency time between behavior and effect is shortened (e.g., Miller, 1968; Shanks & Dickinson, 1991).

Similar to situational information, it is thought that prior knowledge might influence operant conditioning learning (see, Alloy & Tabachnik, 1984; Young, 1995, for overviews). Such prior knowledge can influence operant conditioning learning in a positive or negative way. When prior knowledge is congruent with the association between response behavior and effect that has to be learned, it makes it easier to learn this association. However, when prior knowledge is incongruent with the association between response behavior and effect that has to be learned, it makes it harder to learn the association (e.g., López & Shanks, 2008; Young, 1995). For example, an experience with a behavior that normally does not produce an effect makes the learning of an association between that behavior, when used as response behavior, and an effect more difficult (Young, 1995).

Alloy and Tabachnik (1984) proposed a theoretical framework in which both, situational information and prior knowledge, jointly influence operant conditioning learning. A simplification of this theoretical framework is shown in Table 1 in which situational information and prior knowledge are presented as dichotomies. Negative situational information is defined as situational information that is unfavorable for operant conditioning learning, i.e., when response behavior and effect do not consistently co-occur (contingency) and when there is a long latency time between response behavior and effect (contiguity). Positive situational information is defined as situational information that is favorable for operant conditioning learning, i.e., when response behavior and effect consistently co-occur and when there is a short latency time between response behavior and effect. Prior knowledge could be high in that a subject already has knowledge about the association between response behavior and effect that has to be learned or low in that a subject does not have knowledge about this association.

Within this framework it is thought that operant conditioning learning is hard when, situational information is negative and prior knowledge is low. When prior knowledge is high and situational information is negative subjects are likely to learn the association between response behavior and effect because of their prior knowledge. Moreover, when situational information is positive and prior knowledge is low subjects are likely to learn an association between response behavior and effect because of the situational information. However, when situational information is positive and prior knowledge is high, one of two possible situations might take place. On the one hand, situational information and prior knowledge could be

consistent and suggest the same association between response behavior and effect. In this case the association is very likely to be learned. On the other hand, situational information and prior knowledge could be inconsistent and suggest different associations which could make it very difficult to learn the association between response behavior and an effect. In this case a subject has to decide whether to rely on situational information or prior knowledge to make inferences about the association (Alloy & Tabachnik, 1984).

Table 1

The Influence of Situational Information and Prior Knowledge on Operant Conditioning Learning

Situational Information	Prior Knowledge	
	Low	High
Negative	Not likely to learn the association between the response behavior and effect	Likely to learn the association between the response behavior and effect because of prior knowledge
Positive	Likely to learn the association between the response behavior and effect because of situational information	1) Likely to learn the association between the response behavior and effect because both situational information and prior knowledge imply the same association 2) Not likely to learn the association between the response behavior and effect because situational information and prior knowledge are inconsistent

Note. Adapted from "Assessment of Covariation by Humans and Animals: The Joint Influence of Prior Expectations and Current Situational Information", by L.B. Alloy and N. Tabachnik. (1984), *Psychological Review*, *91*,115. doi:10.1037/0033-295X.91.1.112.

From a developmental perspective it can be argued that the perceptual process that is mainly involved during operant conditioning learning changes from infancy until older adulthood. Here, it can be suggested that bottom-up processes are mainly involved during infants' operant conditioning learning because of their lack on prior knowledge. Moreover, as it is thought that prior knowledge increases over age (increase in pragmatics, e.g., Baltes, 1987) it is reasonable to assume that the involvement of top-down processes during operant conditioning learning increases over the course of human development. Such a developmental

shift from bottom-up to more top-down processing has also been found in other lifespan studies (e.g., Açık, Sarway, Schultze-Kraft, Onat, & König, 2010).

To sum up, it is thought that bottom-up and top-down processes are involved during operant conditioning learning. This suggests that operant conditioning learning is influenced by situational information and prior knowledge. It can be speculated, that bottom-up processes and situational information are important during infants' operant conditioning learning whereas top-down processes and prior knowledge become more important during operant conditioning learning as age increases.

Summary

This literature review on operant conditioning learning in infancy and adulthood showed that there are developmental differences in how operant conditioning learning is assessed. Infants' operant conditioning learning is assessed through behavior indicators. Such behavioral measures of operant conditioning learning might indicate R-O association learning. However, as this behaviorally assessed R-O association learning can be described by a mechanistic process it is unknown whether infants consciously learned that they produced the effect with their own behavior. In contrast, within adult populations this conscious learning of the association between their own behavior and effect is directly measured by verbal indicators.

In addition to the differences in how operant conditioning learning is assessed in infancy and adulthood this review showed that there might be developmental differences in the underlying learning processes that contribute to and in the perceptual processes that are involved during operant conditioning learning. Considering the learning processes, it was discussed that a mechanistic process might be important during operant conditioning learning in infancy whereas higher cognitive processes may be more important during operant conditioning learning in adulthood. However, this might not be the case for all higher cognitive processes in older adulthood. It was argued that higher cognitive processes which are part of mechanics could be less important during operant conditioning learning in older adulthood whereas higher cognitive processes which are part of pragmatics may be more important. Considering the perceptional processes, it was argued that bottom-up processes and situational information might be important during infants' operant conditioning learning whereas top-down processes and prior knowledge could become more important during operant conditioning learning as age increases.

Overview of Dissertation Experiments

Within this dissertation, different experiments with the one and the two disc(s) GCLT are performed to investigate how infants and younger as well as older adults learn to control their visual environment with looking behavior. For an overview of the different experiments conducted see Table 2. In these experiments it is examined how infants, younger, and older adults learn the gaze-contingent association between their looking behavior on a disc and a visual effect. Similar as to what has been done within other operant conditioning tasks, gaze-contingent association learning within the one and the two disc(s) GCLT can be measured behaviorally as well as verbally. Infants' as well as adults' gaze-contingent association learning is assessed behaviorally by measuring looking behavior. Examples of looking behavior investigated are the looking behavior on the disc that triggers new stimuli (response behavior) and visual expectations to the new upcoming stimuli. Additionally to this behaviorally assessed gaze-contingent association learning, adults' gaze-contingent association learning is measured verbally by administering a questionnaire.

Table 2

Overview of Experiments

Experiment	Paradigm	Experimental Condition		Age Group	Chapter
1	One disc GCLT			Infants	5
2	Two discs GCLT			Infants and young adults	5
3	Two discs GCLT		Contiguity short vs. long	Young adults	6
4	Two discs GCLT			Younger and older adults	6
5	Passive Habituation-Dishabituation			Infants	7
6	One disc GCLT Habituation-Dishabituation			Infants	7

Chapter 5 consists of the first line of experiments in which infants and young adults are for the first time tested within the one and the two disc(s) GCLT. In Experiment 1 it is examined how infants learn the gaze-contingent association within the one disc GCLT whereas in Experiment 2 it is investigated how infants as well as young adults learn the gaze-contingent association within the two discs GCLT. These experiments show whether infants and adults are able to learn gaze-contingent associations within GCLT set-ups and if there are developmental differences.

Within the second line of experiments (Chapter 6), the learning of the gaze-contingent association within the two discs GCLT is further investigated with adult subjects. In two experiments, perceptual factors that might influence adults' gaze-contingent association learning are investigated. In Experiment 3 it is examined whether the learning of the gaze-contingent association within the two discs GCLT by young adults is influenced by contiguity (situational information). Young adults are tested in the two discs GCLT with a long or a short latency time. In Experiment 4, the influence of prior knowledge related cues on learning the gaze-contingent association within the two discs GCLT in younger and older adults is tested. Younger and older adults are tested in different versions of the two discs GCLT that varied in their appearance. The red discs were replaced by green discs and grey switches in order to implement prior knowledge related cues. These experiments show whether situational information and prior knowledge related cues influences adults' gaze-contingent association learning within GCLT set-ups. Moreover, they reveal if there are developmental differences in younger and older adults' gaze-contingent association learning within such set-ups.

In the third line of experiments (Chapter 7) the one disc GCLT is further tested with infants. In this chapter the main focus is not on the learning of the gaze-contingent association per se, however, it is examined whether the one disc GCLT can be used to give infants active control within a passive looking behavior task in which they normally have no control. In this chapter it is discussed whether such active control changes infants' habituation-dishabituation learning. To this end, a passive habituation-dishabituation experiment (Experiment 5) is compared to a one disc GCLT habituation-dishabituation experiment (Experiment 6). In both experiments the same female faces are used as stimuli. In these experiments infants looking behavior on the female faces is examined and a comparison of the looking behavior on the female faces between experiments is made. These experiments provide further information on infants' gaze-contingent association learning within the one disc GCLT.

Taken together, these experiments provide information on how infants and younger as well as older adults learn the gaze-contingent association within the one and the two disc(s) GCLT. They show whether such tasks can be used to give infants, younger, and older adults active control over their visual environment with looking behavior. Furthermore, they reveal if there are developmental differences in learning to control the visual environment with looking behavior. To be more specific, these experiments show if there are developmental differences in learning gaze-contingent associations within GCLT set-ups. Last but not least, the experimental results can be discussed against background theories of developmental differences in the underlying learning processes that contribute to and in the perceptual processes that are involved during operant conditioning learning.

<center>**Chapter 5**</center>

<center>**Learning to Control the Visual Environment with Looking Behavior within the GCLT:**</center>
<center>**Infants and Young Adults**</center>

This chapter consists of the first experiments in which the GCLT is applied to give subjects control over their visual environment. In Experiment 1 infants are tested with the one disc GCLT whereas in Experiment 2 infants as well as young adults are tested with the two discs GCLT.

Experiment 1: One Disc GCLT in Infancy

Introduction

In order to be in control of their visual environment within the one disc GCLT infants' have to learn that there is a gaze-contingent association between their looking behavior at a red disc and the appearance of a stimulus. As this is the first gaze-contingent association learning experiment with infants it is explored whether 6- and 8-month-old infants are able to learn such a gaze-contingent association. Similar as to what has been done within other operant conditioning studies infants' gaze-contingent association learning is examined behaviorally (e.g., Kenward, 2010; Rovee & Rovee, 1969; Siqueland & Lipsitt, 1966) by assessing infants' looking behavior. The looking behavior investigated is the looking behavior on the disc that triggers new stimuli, average fixation duration on disc and stimuli, and visual expectations to the new upcoming stimuli. These behavioral indicators provide information on whether infants learn an R-O association, and therefore on whether infants might learn that there is an association between their own looking behavior and the appearance of the new stimulus.

Method

Participants. A sample of $N = 29$ (20 female) 6-month-old and $N = 6$ (3 female) 8-month-old infants visited the laboratory. As $n = 5$ 6-month-old infants had to be excluded because of fuzziness ($n = 1$), calibration problems ($n = 3$) or a software problem ($n = 1$), data from $n = 24$ 6-month-old infants ($M = 186$ days, $SD = 3.89$ days; 17 female) remained. As no 8-month-old infants had to be excluded, data from $n = 6$ 8-month-old infants ($M = 245$ days, $SD = 3.27$ days; 3 female) was used for calculations. All infants were healthy and had no known medical problems (birth week, birth weight, and APGAR-score were within standard values). None of the caregivers of the infants reported any known visual problems. Participants were recruited via informational flyers or locally distributed advertisements in

newspapers and family magazines. The caregivers of the participants voluntarily[3] contacted us when they were interested in attending a study. All the infants that participated lived in the Frankfurt/Main metropolitan area and received a small toy as compensation.

Laboratory settings. The experiment was conducted in the developmental psychology lab of the Goethe-University in Frankfurt/Main, Germany. Figure 11 shows a schematic overview of the eye tracker laboratory settings.
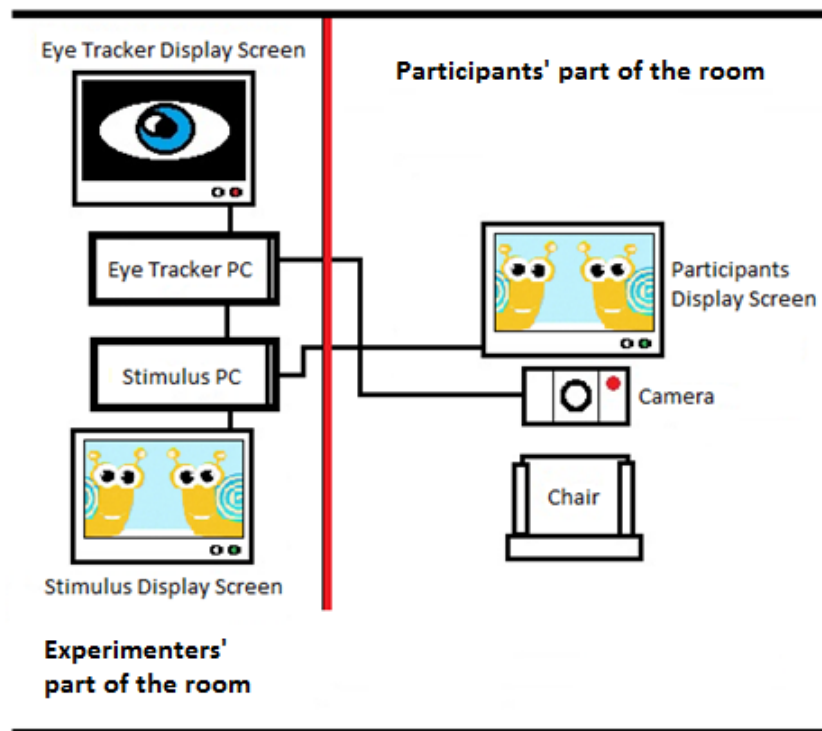
Figure 11. Schematic overview of the eye tracker laboratory settings. The red line indicates the separate room. Adapted from "Novelty Preference and Operant Conditioning in Adults: An Eye-Tracker Study", by S. Betz. (2010).

The laboratory consists of an experimenter and participant part of the room. Participants had to sit on the chair in the participant's part of the room. Participating infants were seated in an infant-seat placed on their parent's lap. Infants had to look at the participant's display screen, where the eye tracker camera was attached underneath. The experimenter was sitting in the experimenter part of the room. The experimenter was able to monitor the infants' eye movement behavior on the eye tracker display screen. Furthermore

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[3] This experiment was conducted in line with the Ethical Principles of Psychologists and Code of Conduct of the American Psychological Association.

the experimenter saw on the stimulus display screen, which stimuli were presented to the participants. The eye tracker experiment was started from the stimulus computer and eye tracker data was collected on the eye tracker computer. Before the infants came into the room moving snails were presented to directly catch the infants' attention.

Eye tracker. A SR Research EyeLink® 1000 Remote eye tracker provided eye tracking data during the experiment. The system is composed of a 17 inch flat-screen monitor (resolution 1024 x 768) with an eye tracking camera recording the reflection of an infrared light source on the cornea relative to the pupil at a frequency of 500 Hz. The average accuracy of this eye tracking system is 0.5° approximating to a 0.5 cm area on the display screen with a viewing distance of 60 cm. The eye tracking system allowed for moderate head movements without accuracy reduction: 22 cm x 18 cm x 20 cm (horizontal x vertical x depth). Blink or occlusion recovery was faster than 3 ms ($SD < 1.2$ ms). The eye tracking system uses a 9-sample moving filter for smoothing the eye tracking data. The system analyzes eye position data into meaningful events and states (saccades, fixations, and blinks) by computing instantaneous velocity and acceleration and compares these to the velocity and acceleration thresholds. These thresholds are 30°/s for velocity and 8000°/s^2 for acceleration. If either is above threshold, a saccade signal is generated (SR Research Ltd., 2005-2009). If gaze was on the display screen (i.e., participant not blinking or looking away) and no saccade signal was generated, the eye tracker recorded a fixation towards the current gaze location.

During the eye tracking experiment the eye tracker had to be adjusted in such a way that the infants' distance to the display screen was approximately 60 cm, pupil and cornea reflection were visible and that the infants' gaze was stable. Head distance is accurately measured using a small target sticker placed on the infant's forehead (see Figure 7). Before the gaze-contingent eye tracker experiment started a calibration and validation procedure had to be performed. During the calibration/validation process (performed using manual mode) a looming, circular shaped calibration/validation target (maximum size 170 x 170 pixels) appeared at three different locations (middle coordinates in pixels: $x_{T1} = 512$, $y_{T1} = 65$; $x_{T2} = 962$, $y_{T2} = 702$; $x_{T3} = 62$, $y_{T3} = 702$) of the display screen. A fixation at a calibration target was judged as correct if the spatial pattern of recorded gaze locations corresponded with the pattern of calibration targets being presented. A fixation at a validation target was judged as correct if the dot indicating the recorded gaze location during calibration and the dot indicating the location of the gaze being recorded during validation were (nearly) overlapping. An exclusion criterion was a 1.5° average error during the validation of the calibration phase, which corresponds to a 1.5 cm area on the display screen with a viewing distance of 60 cm.

Infants who were bad calibrated were excluded from data analysis, and therefore only the data of infants that had a fair or good calibration were used.

Stimuli and gaze-contingent set-up. The one disc GCLT set-up consists of a red disc at the right side and a stimulus presentation frame at the left side of the display screen. 28 different animal photographs could be presented in the stimulus presentation frame. At a viewing distance of 60 cm, the 200 x 200 pixel red disc subtended 6.1° visual angle horizontally x 6.7° visual angle vertically (middle coordinates in pixels: x = 850, y = 384) and the 450 x 300 pixel animal photographs (left-top coordinates in pixels: x = 30, y = 234) subtended 13.4° visual angle horizontally x 10.0° visual angle vertically. The stimuli were presented against a white background (see Figure 12). Areas of interest were manually defined to exactly match the red disc and animal photographs.
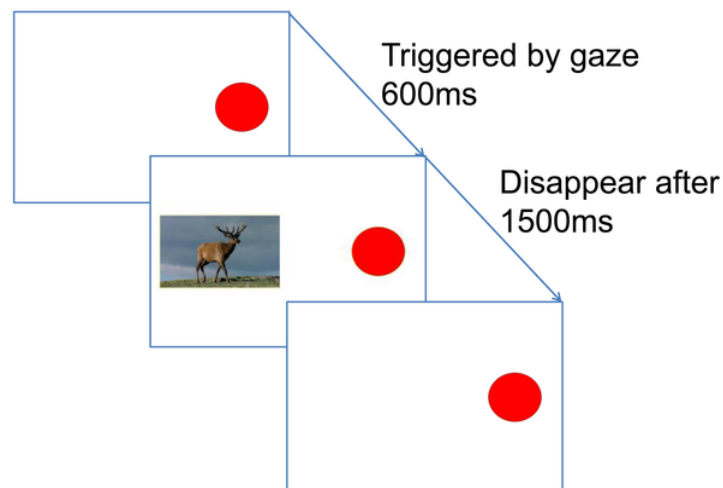
Figure 12. Example of stimulus set-up one disc GCLT. Taken from "Infants in Control: Rapid Anticipation of Action Outcomes in a Gaze-Contingent Paradigm", by Wang et al. (2012), PLoS ONE, 7, e30884. doi:10.1371/journal.pone.0030884.g001.

By fixating the red disc at the right side of the display screen infants triggered the appearance of an animal photograph in a predefined stimulus presentation frame located at the left side of the display screen. The appearance of the photograph was accompanied by an acoustic sound. Sound and photograph occurred with a delay of approximately 600 ms (latency time) after the infant fixated the disc and the photograph stayed on the display screen for 1.5 s before it disappeared (see Figure 12). After fixating the red disc and triggering an

animal photograph the red disc did not function for 1 s. The one disc GCLT lasted 1 min and the different animal photographs were randomly presented.

Procedure. After welcoming, explaining the study procedure, explaining the eye tracking procedure and obtaining written informed consent, infants immediately took part in the eye tracking study. The eye tracker was adjusted and the calibration/validation procedure was conducted. After successful calibration and validation, the gaze-contingent eye tracking experiment started. The session took approximately 30 min and finished by thanking the infant and caregiver for their participation and rewarding the infant with a little toy.

Results

Effects of gender. Preliminary analyses of gender on any of the variables used for subsequent analyses obtained no significant differences. Therefore, data was collapsed across this variable for subsequent analyses.

Looking behavior on the disc that triggers new stimuli. 6- and 8-month-old infants' looking behavior on the disc that triggered new stimuli was analyzed and compared. Within a minute infants' frequently looked at the disc that resulted in the appearance of a new animal photograph ($M = 16.30$, $SD = 4.94$). An independent t-test showed that 8-month-old infants' ($M = 20.50$, $SD = 4.42$) looking behavior on the disc that triggered new stimuli was significantly higher than that of 6-month-old infants ($M = 15.25$, $SD = 5.01$), $t(28) = -2.54$, $p < .05$, $r = .43$.

Average fixation duration on disc and stimuli. A more detailed analysis of infants' looking behavior was made in that infants' average fixation duration on the constantly presented disc and the animal photographs that were only presented for 1.5 were investigated. A paired t-test showed that infants' average fixation duration on the animal photographs ($M = 535.34$, $SD = 197.89$) was longer than on the disc ($M = 397.54$, $SD = 123.88$), $t(29) = -4.03$, $p < .001$, $r = .60$. No difference between 6- and 8-month-old infants' average fixation duration on the disc, $t(28) = -1.22$, ns (6m, $M = 383.86$, $SD = 127.41$; 8m, $M = 452.22$, $SD = 99.25$) and the animal photographs, $t(28) = .27$, ns (6m, $M = 540.25$, $SD = 215.56$; 8m, $M = 515.70$, $SD = 113.23$) were found.

Expectancies to the new upcoming stimuli. In order to measure infants' expectancies to the new upcoming animal photographs, reaction times and anticipations to these photographs were analyzed. Here, anticipations indicate that infants expected the new upcoming stimulus to appear. A standard criterion for calling reaction times anticipations is 200 ms (Haith et al., 1988). According to the 200 ms criterion infants' average percentage of

anticipations was 44% (SD = 24.01). An independent *t*-test showed no difference in average percentage of anticipation for 6- (*M* = 46.00, *SD* = 25.18) and 8-month-old (*M* = 35.84, *SD* = 18.08) infants, $t(28) = .92$, *ns*.

To see whether infants' reaction times decrease with an increase in number of triggered stimuli a linear and inverse linear model were fitted on the data. These curve estimations show that infants' average reaction times decrease with an increase in the number of triggered stimuli as the linear curve is marginal significant, $F(1,13) = 4.48$, $p = .054$, $R^2 = .26$, and the inverse linear curve is significant, $F(1,13) = 6.77$, $p < .05$, $R^2 = .34$. Both curve estimations are provided in Figure 13.
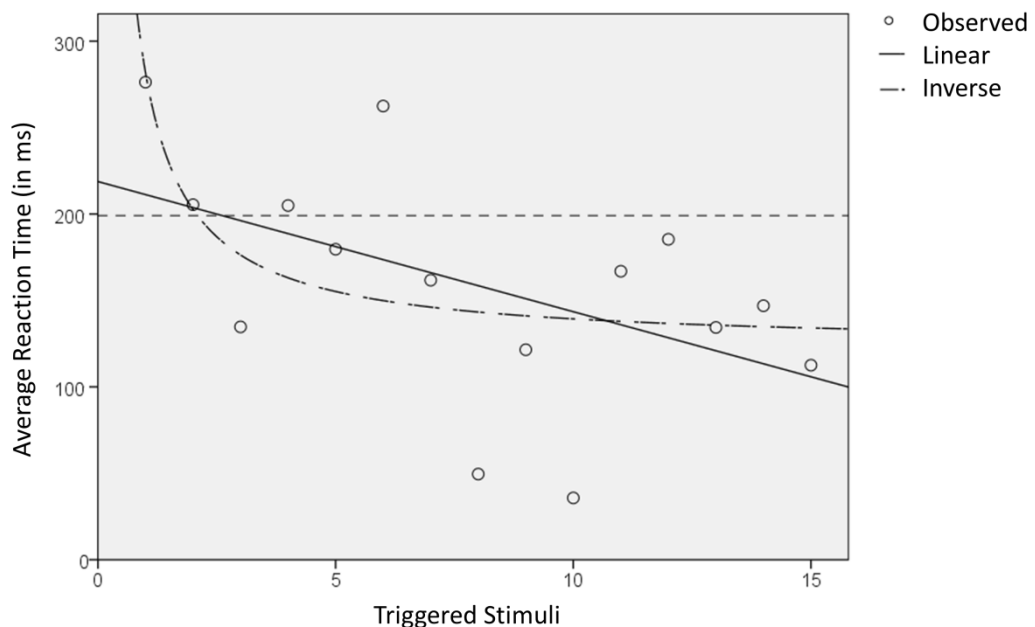
Figure 13. Average reaction time as a function of triggered stimuli. Only the first 15 triggered stimuli are plotted, since only a minority of infants saw more than 16 stimuli. The dashed line is the 200 ms criterion for anticipations. A linear curve (y = -7.53*x+218.77) and an inverse curve (y = 123.5/x+158.35) were fitted to the infants' average reaction times.

Conclusion

In this experiment it was explored whether 6- and 8-month-old infants are able to learn a gaze-contingent association within the one disc GCLT. This first experiment suggests that

6- and 8-month-old infants are able to learn the gaze-contingent association within the one disc GCLT. The results showed that the infants frequently looked at the disc and that 8-month-old infants did this significantly more often than 6-month-old infants. Moreover, a more detailed examination of infants' looking behavior showed that infants' average fixation duration on the animal photographs that were only presented for 1.5 s was higher than on the constantly presented red disc. This finding demonstrates that infants did not merely look at the disc as it was highly salient per se (as spontaneous looking behavior) which might indicate R-O instead of S-R association learning.

Additional evidence of infants' R-O association learning within the one disc GCLT is provided by expectation analysis. The results demonstrate that infants show anticipatory looking behavior to the new upcoming stimuli within a few trials. Therefore, this experiment suggests that infants learned the R-O association between looking at the red disc and the appearance of a new stimulus within the one disc GCLT as they expected the outcome of looking at the red disc very rapidly.

The findings of this experiment indicate that infants are able to learn an R-O association between specific looking behavior and a visual effect within the one disc GCLT. However, as this behavioral assessed gaze-contingent association learning can be described by a mechanistic process it remains unclear whether infants consciously learned that their own behavior produced the effect or whether this learning was unconscious.

Experiment 2: Two Discs GCLT in Infancy and Young Adulthood

Introduction

Experiment 1 suggests that infants are able to learn the gaze-contingent association within the one disc GCLT. The results of Experiment 1 indicate R-O association learning as it was found that infants only shortly looked at the disc and that they expected the new upcoming stimulus. However, in this one disc version of the task it might have been that the experimental set-up evoked infants' looking behavior on the disc. Here, it might have been that infants started to look at the disc as it was the only stimulus left on the display screen after the animal photograph, which was only presented for 1.5 s, disappeared.

The two discs GCLT addresses this issue by presenting a second similar looking but non-functioning disc and by presenting the stimuli for a longer period of time. In this version of the task subjects have to discriminate between the functioning and non-functioning discs in order to learn the gaze-contingent association. Such discriminatory behavior provides evidence that an increase in looking behavior on the disc might be due to R-O association

learning instead of S-R association learning. Moreover, in this version of the task the animal photographs did not disappear after 1.5 s, however, they faded out over an interval of approximately 17 s. The longer presentation of the animal photographs causes other visual stimuli to be present on the display screen most of the time than only the discs. Therefore, this longer presentation of the stimuli controls for the possibility that looking behavior is automatically directed to the discs.

In Experiment 2 it is investigated whether 6- and 8-month-old infants as well as young adults learn the gaze-contingent association within the two discs GCLT. Infants' as well as adults' gaze-contingent association learning is measured behaviorally by assessing looking behavior. Firstly, the interval times between looking at the functioning disc that triggered new stimuli (click intervals) are examined. Secondly, the looking behavior on the functioning disc is compared to the looking behavior on the non-functioning disc. Additionally to this behaviorally assessed gaze-contingent association learning, adults' gaze-contingent association learning is measured verbally by administering a questionnaire.

Method

Participants. A sample of $N = 28$ (12 female) 6-month-old and $N = 23$ (11 female) 8-month-old infants visited the laboratory. As $n = 11$ 6-month-old infants had to be excluded because of fuzziness ($n = 5$), excessive movement ($n = 3$), sleeping ($n = 1$) or calibration problems ($n = 2$), data $n = 17$ 6-month-old infants ($M = 187$ days, $SD = 3.46$ days; 7 female) remained. As $n = 7$ 8-month-old infants had to be excluded because of excessive movement ($n = 5$), calibration problems ($n = 1$) or a software problem ($n = 1$), data from $n = 16$ 8-month-old infants ($M = 245$ days, $SD = 3.54$ days; 7 female) remained. All infants were healthy and had no known medical problems (birth week, birth weight, and APGAR-score were within standard values). None of the caregivers of the infants reported any known visual problems. As in Experiment 1, participants were recruited via informational flyers or locally distributed advertisements in newspapers and family magazines. The caregivers of the infant participants voluntarily[3] contacted us when they were interested in attending a study. All the infants that participated lived in the Frankfurt/Main metropolitan area and received a small toy as compensation.

A sample of $N = 28$ (23 female) adults participated in this study. As $n = 3$ adults had to be excluded because of calibration/validation problems, data from $n = 25$ ($M = 26.00$ years, $SD = 6.99$ years; 20 female) adults remained. All adult participants were students at the Goethe-University, Frankfurt/Main, Germany, who voluntarily[3] participated. Each of the adult

participants confirmed that they had normal or corrected-to-normal vision on the eye used for eye tracking. Moreover, they partly received course credit for their participation.

Laboratory settings and eye tracker. Similar to Experiment 1, the experiment was conducted in the developmental psychology lab of the Goethe-University in Frankfurt/Main, Germany. The same eye tracker as in Experiment 1 provided eye tracking data. As in Experiment 1, infants had a 3-point calibration validation procedure. However, adult participants received a 5-point calibration validation procedure (middle coordinates in pixels: $x_{T1} = 512$, $y_{T1} = 384$; $x_{T2} = 512$, $y_{T2} = 65$; $x_{T3} = 512$, $y_{T3} = 702$; $x_{T4} = 62$, $y_{T4} = 384$; $x_{T5} = 962$, $y_{T5} = 384$). Moreover, the same calibration exclusion criterion that was used for the infants in Experiment 1 was used for the infant and the adult participants in the present study.

Stimuli, gaze-contingent set-up, and materials. The gaze-contingent set-up consists of a synchronous presentation of two red discs with little white crosses in the center (positioned left and right from the display screen's center) and a stimulus presentation frame in the middle of the display screen. 30 different animal photographs could be presented in the stimulus presentation frame. At a viewing distance of 60 cm, a 180 x 180 pixel red disc subtended 5.4° visual angle horizontally x 6.0° visual angle vertically (middle coordinates in pixels: left: $x = 100$, $y = 384$; right: $x = 924$, $y = 384$) and the 396 x 260 pixel animal photographs (left-top coordinates in pixels: $x = 312$, $y = 250$) subtended 12.4° visual angle horizontally x 8.7° visual angle vertically. The stimuli were presented against a white background (see Figure 14). Areas of interest were manually defined to exactly match the red discs and animal photographs.
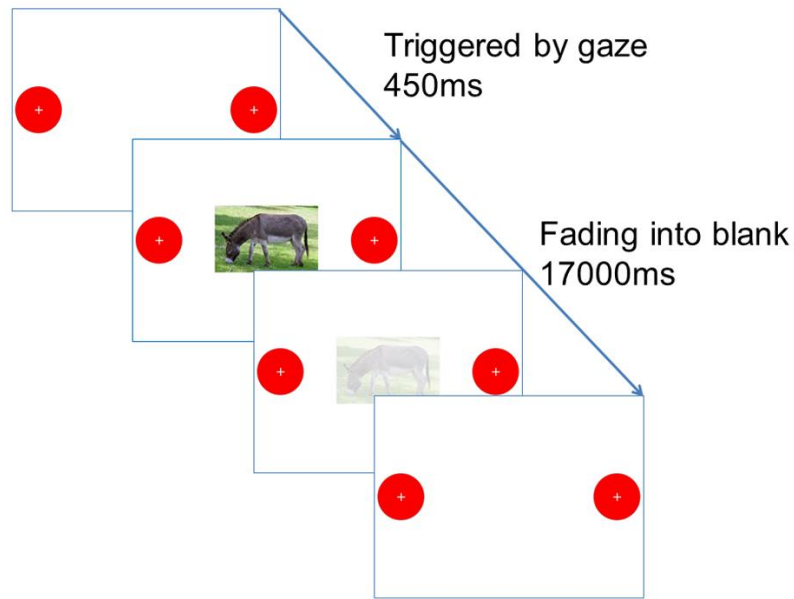
Figure 14. Example of stimulus set-up two discs GCLT. Taken from "Infants in Control: Rapid Anticipation of Action Outcomes in a Gaze-Contingent Paradigm", by Wang et al. (2012), *PLoS ONE, 7,* e30884. doi:10.1371/journal.pone.0030884.g005.

During the two discs GCLT one of the two discs (counterbalanced position across participants) functioned as a switch. Participants had to fixate the functioning disc in order to trigger the appearance of an animal photograph in the stimulus presentation frame at the center of the display screen. The appearance of the photograph was accompanied by an acoustic sound. Sound and photograph occurred with a delay of approximately 450 ms (latency time) after the participant fixated the functioning disc. The photographs of the animals presented in the stimulus presentation frame slowly faded away over an interval of approximately 17 s (100 frames video; frames per second was 6) or were replaced by a new one when the participant fixated the functioning disc again (see Figure 14). Slow fading photographs were used to make sure that participants did not merely look at the discs because nothing else was on the display screen. After fixating the red disc and triggering an animal photograph the red disc did not function for 1 s. The experiment terminated either after presentation of 30 animal photographs (at randomly presented) or after 5 min of total experimental time.

A questionnaire (see Appendix Questionnaire A) was administered to the adult participants in order to assess their conscious gaze-contingent association learning. This questionnaire assessed whether the adult participants had learned the association between their looking behavior and the visual effect. The questionnaire first assessed the participant's

general feelings and thoughts about the experiment. Centrally important, participants' understanding of the function of the two discs was assessed by asking (1) if they knew what the study was about, (2) whether they thought of the red discs having any specific function, (3) whether they felt as if he or she could influence or control the experiment with looking behavior, (4) and whether they detected that if he or she looked at a specific red disc a new animal photograph occurred. Lastly, the participants were asked to explain the functions of the discs and on which side the functioning and non-functioning discs were placed. Moreover, if participants were able to explain the functions of the discs, it was asked if they had already noticed this during the two discs GCLT part of the study.

Procedure. After welcoming, explaining the study procedure, explaining the eye tracking procedure and obtaining written informed consent, participants immediately took part in the eye tracking study. Prior to testing, it was made sure that all caregivers or participants understood what eye tracking was. However, the adult participants were not instructed about the gaze-contingent set-up. The eye tracker was adjusted and the calibration/validation procedure was conducted. After successful calibration and validation, the two discs GCLT experiment started. The session took approximately 30 min for the infants and finished by thanking the caregiver for participation and rewarding the infant with a little toy. For the adult participants the session took approximately 45 min as they had to answer the questionnaire. The session finished by explaining the experiment's purpose and thanking the participants for their participation.

Results

Effects of gender. Preliminary analyses of gender obtained no significant differences. Therefore, data was collapsed across this variable for subsequent analyses.

Questionnaire: Solvers and non-solvers. Adults' conscious learning of the gaze-contingent association was measured with the questionnaire. Based on the questionnaire adult participants were divided into solvers and non-solvers. Solvers were participants that were able to verbally explain the function of the discs; this means they were able to explain that they had to look at a specific disc (left or right) in order to trigger a new animal photograph. Participants were only classified as solver if they had consciously noticed the functioning disc during the two discs GLT part of the study. Non-solvers were unable to verbally explain the functions of the discs; they did not consciously notice that they could control the display screen with looking behavior and could not state which disc functioned as a switch.

Somewhat surprisingly, the questionnaire revealed that only 36% ($n = 9$) of the adult participants could be classified as solvers. Preliminary analyses showed no effects of side of functioning disc on percentage of solvers.

Looking behavior: Click interval data. Click interval data, defined as periods of time between looking at the functioning disc that triggered new stimuli (measured in ms), for the adults solvers, adult non-solvers and infants were examined. As the click interval data was not normally distributed non-parametrical tests were performed.

Figure 15 shows the click interval distributions of adult solvers, adult non-solvers, and infants. A Mann-Whitney test revealed that adult solvers (*Mdn* = 4272) had significantly shorter click intervals than adult non-solvers (*Mdn* = 17287), $U = 11061.00$, $z = -9.28$, $p < .001$, $r = -.45$. Interestingly, it was also found that the click interval data of the infants (*Mdn* = 4857) matched the data of adult solvers, $U = 89041.50$, $z = -.93$, *ns*, but did not match the data of adult non-solvers, $U = 36761.00$, $z = -11.26$, $p < .001$, $r = -.36$. Therefore, infants and adult solvers showed many click intervals shorter than 10 s whereas adult non-solvers did not. These short click intervals indicate that infants and adult solvers frequently looked at the functioning disc that resulted in the triggering of new stimuli whereas non-solvers did not show this looking behavior so frequently.
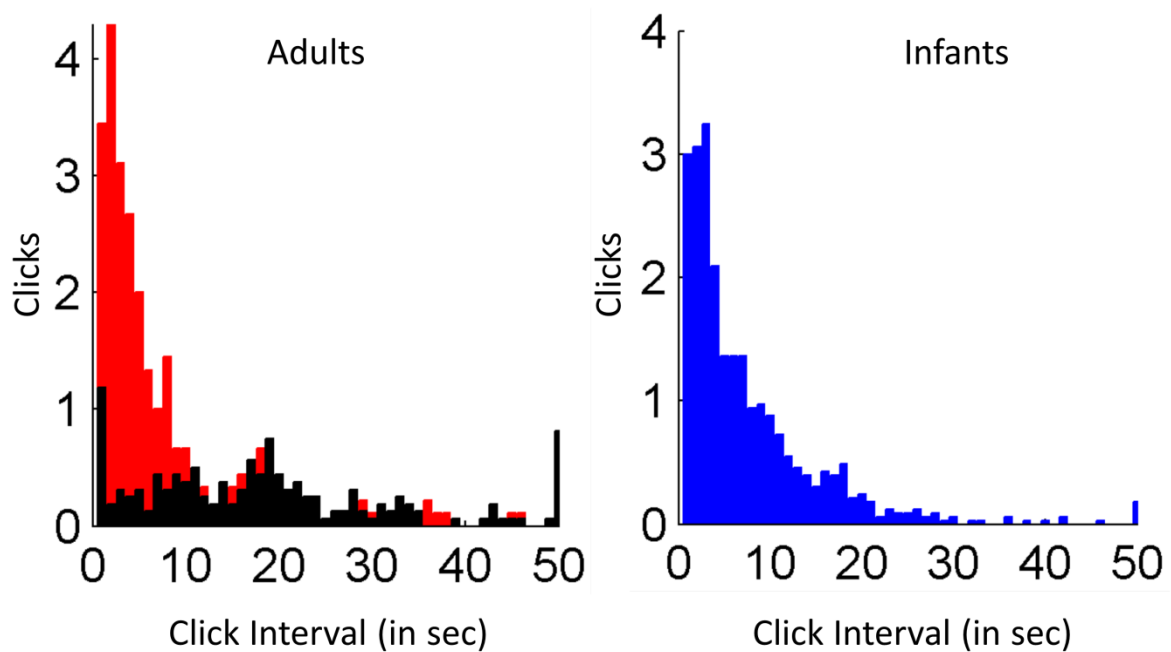
Figure 15. Click interval distribution of adult solvers (red), adult non-solvers (black), and infants (blue). Adapted from "Infants in Control: Rapid Anticipation of Action Outcomes in a Gaze-Contingent Paradigm", by Wang et al. (2012), *PLoS ONE*, *7,* e30884. doi:10.1371/journal.pone.0030884.g006.

Looking behavior: Functioning and non-functioning disc pattern. To identify specific differences in the usage between the two discs, looking behavior on the function disc (response behavior) is compared to the looking behavior on the non-functioning disc. To be more specific looking behavior patterns to the functioning and non-functioning disc were investigated. A functioning disc pattern is defined as a sequence of saccades leading from the animal photograph area to the functioning disc and back to the animal photograph area. A non-functioning disc pattern is defined as a sequence of saccades leading from the animal photograph area to the non-functioning disc and back to the animal photograph area.

Figure 16 shows the functioning and non-functioning disc patterns for adult solvers, adult non-solvers, and infants. A one-way ANOVA with group (adult solvers vs. adult non-solver vs. infants) as the independent variable and functioning disc pattern as the dependent variable revealed a main effect for group, $F(2, 55) = 11.23$, $p < .001$, $\eta_p^2 = .29$. Adult solvers ($M = 23.78$, $SD = 5.14$) made more functioning disc patterns than adult non-solvers ($M = 10.88$, $SD = 4.87$), $t(23) = -6.24$, $p < .001$, $r = .79$, and infants ($M = 16.24$, $SD = 7.50$),

$t(40) = -2.83$, $p < .01$, $r = .41$. Furthermore, infants made more functioning disc patterns than adult non-solvers, $t(47) = 2.60$, $p < .05$, $r = .35$.
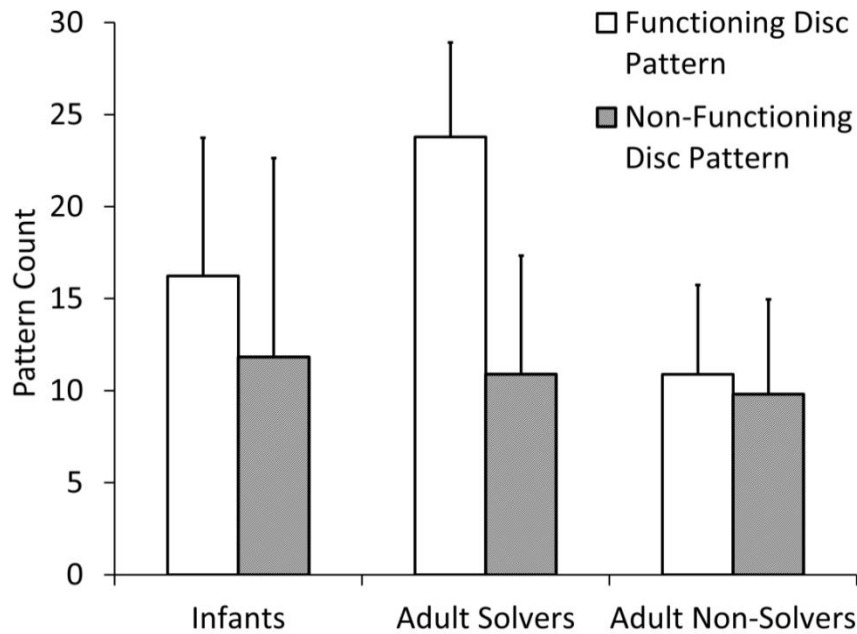
Figure 16. Functioning and non-functioning disc patterns (+ SD) of infants, adult solvers and adult non-solvers.

A one-way ANOVA with group as the independent variable and non-functioning disc pattern as the dependent variable did not reveal a main effect for group, $F(2, 55) = .27$, *ns*. No difference in non-functioning disc pattern between adult solvers ($M = 10.89$, $SD = 6.45$), adult non-solvers ($M = 9.81$, $SD = 5.15$), and infants ($M = 11.82$, $SD = 10.81$) were found (see Figure 16).

A repeated measure (RM) ANOVA with functioning and non-functioning disc pattern as repeated measure variables and group as the independent variable revealed that more functioning ($M = 15.93$, $SD = 7.65$) than non-functioning ($M = 11.12$, $SD = 8.90$) disc patterns were made, $F(1, 55) = 15.57$, $p < .001$, $\eta_p^2 = .22$. However, an interaction effect showed that this effect is influenced by group, $F(2, 55) = 3.84$, $p < .05$, $\eta_p^2 = .12$. Paired *t*-tests showed that adults solvers and infants made significant more functioning than non-functioning disc patterns, $t(8) = 6.26$, $p < .001$, $r = .91$, and, $t(32) = 2.12$, $p < .05$, $r = .35$, respectively. No difference in functioning and non-functioning disc patterns for the adult non-solvers, $t(15) = .54$, *ns*, was found.

Conclusion

In this experiment it was investigated whether 6- and 8-month-old infants as well as young adults learn the gaze-contingent association within the two discs GCLT. The results of this experiment showed that 6- and 8-month-old infants frequently looked at the functioning disc. Moreover, it was found that they made more functioning than non-functioning disc patterns. This demonstrates that infants are able to discriminate between the functioning and non-functioning discs, which suggests that they learned an R-O association between looking at the disc and the appearance of an animal photograph within the two discs GCLT. Therefore, this experiment provides additional evidence that infants are able to learn a gaze-contingent association between looking behavior at a red disc and the appearance of an animal photograph within GCLT set-ups. Infants are not only able to learn such a gaze-contingent association within the one disc GCLT but this experiment indicates that they are also able to learn such a gaze-contingent association in the two discs GCLT.

Somewhat surprisingly, it was also found that the learning of the gaze-contingent association within the two discs GCLT was difficult for adult participants. Only 36% of the adults were classified as solvers which indicates that only 36% of the adults learned the gaze-contingent association within the two discs GCLT consciously.

The results of this experiment also revealed that a verbal expression of the gaze-contingent association corresponded to specific looking behavior on the discs. Adult solvers had shorter click intervals and made more functioning disc patterns than adult non-solvers. Moreover, adult solvers made more functioning than non-functioning disc patterns whereas this preference was not found for non-solvers. This finding suggests that looking behavior might indicate that a gaze-contingent association is learned consciously. However, it has to be kept in mind that looking behavior is an indirect measure of gaze-contingent association learning and that the only measure that provides certain evidence that subjects learned the gaze-contingent association consciously is their verbal expression of the association.

When comparing click interval data and functioning and non-functioning disc-patterns of infants with adult solvers and non-solvers it was found that infants' looking behavior closely matched the looking behavior of adult solvers whereas it did not match the looking behavior of adult non-solvers. To speculate, this finding suggests that some infants might have learned the gaze-contingent association consciously.

To conclude, this experiment showed that infants learned to look at only one of the two red discs that triggered the appearance of an animal photograph. This learning indicates

R-O association learning. Moreover, it was found that this R-O association is not learned by a large group of adult non-solvers. This finding demonstrates that there are developmental differences in learning to control the visual environment with looking behavior within the two discs GCLT.

Discussion

In this chapter it was investigated whether infants and young adults learn to control their visual environment with looking behavior within the GCLT set-ups. More specifically it was examined whether infants and young adults learned the gaze-contingent association within the one or two disc(s) GCLT. Infants' as well as adults' gaze-contingent association learning was assessed behaviorally by measuring looking behavior. Additionally, adults' gaze-contingent association learning was measured verbally by administering a questionnaire.

Taken together, the results of Experiments 1 and 2 suggest that infants are able to learn a gaze-contingent association between looking behavior and a visual effect. The results of Experiment 1 indicate that infants learn the gaze-contingent association within the one disc GCLT very quickly. Moreover, Experiment 2 suggests that infants are also able to learn such a gaze-contingent association when a second non-functioning disc is presented (two discs GCLT). However, the results of Experiment 2 also showed that this learning might be difficult for adult participants. Therefore, developmental differences in learning to control the visual environment with looking behavior within the two discs GCLT were found.

To speculate, these dissimilarities found between infants and young adults might be due to developmental differences in the learning processes that contribute to and in the perceptual processes that are involved during gaze-contingent association learning. Here, it can be argued that higher cognitive processes and prior knowledge (top-down perceptual processes) play a smaller role in infants' gaze-contingent association learning than in adults' gaze-contingent association learning. For the present experiment it might have been that incongruent prior knowledge about the task (having learned over many years that looking at a display screen does not produce any effect on the environment) could have hindered the learning of the gaze-contingent association for adults (e.g., Alloy & Tabachnik, 1984; López & Shanks, 2008; Young, 1995), whereas infants' lack of prior knowledge might have made the learning of such a gaze-contingent association easier for them.

In conclusion, this chapter provides the first evidence for the ability of the one and the two disc(s) GCLT to be used by infants and young adults to control their visual environment with looking behavior. However, developmental differences between infants and young adults

were found. This control over the visual environment with looking behavior might be easier learned by infants than by young adults. These gaze-contingent association learning differences found between infants and young adults could be due to developmental differences in the learning processes that contribute to and in the perceptual processes that are involved during such learning.

Acknowledgements

Chapter 6

Learning the Gaze-Contingent Association within the Two Discs GCLT in Adulthood:
The Influence of Perceptual Processes as well as Age in Adulthood

In Experiment 2 it was demonstrated that the gaze-contingent association between looking behavior and a visual effect within the two discs GCLT was hard to learn for a large group of young adult participants. These young adult non-solvers did not consciously learn that they had to look at a specific disc in order to trigger the appearance of a new animal photograph. Moreover, their looking behavior also indicates that they did not learn the gaze-contingent association as they were not looking at the functioning disc. Therefore, it was concluded that it might be hard for young adults to learn to control the display screen with looking behavior within the two discs GCLT.

In the present chapter, gaze-contingent association learning within the two discs GCLT is further investigated with adults. In Chapter 4 (see pages 43-46), perceptual processes that might influence operant conditioning learning were discussed. The present chapter consists of two experiments in which it is investigated whether perceptual factors influence adults' gaze-contingent association learning within the two discs GCLT. In Experiment 3 it is thereby examined whether the learning of the gaze-contingent association within the two discs GCLT by young adults is influenced by contiguity (situational information). In Experiment 4, the influence of prior knowledge related cues on the learning of the gaze-contingent association within the two discs GCLT by younger and older adults is tested.

Experiment 3: Two Discs GCLT in Young Adulthood and the Influence of Contiguity

Introduction

In this experiment it is investigated whether the learning of the gaze-contingent association within the two discs GCLT by young adults is influenced by *contiguity*. As has been addressed in Chapter 4 (see pages 43-44), different studies have shown that operant conditioning learning gets worse when the *latency time* between behavior and effect is extended (e.g., Miller, 1968; Shanks & Dickinson, 1991). In the present experiment two latency conditions (approx. 100 vs. approx. 450 ms) are tested and it is hypothesized that a shorter latency time will make it easier to learn the gaze-contingent association within a two discs GCLT.

Similar as to what was done in Experiment 2, adults' gaze-contingent association learning is measured behaviorally by assessing looking behavior and verbally by

administering a questionnaire. Therefore, it is investigated whether contiguity influences adults' behaviorally assessed and verbally expressed gaze-contingent association learning. The results of Experiment 2 showed that a verbal expression of the gaze-contingent association corresponded to specific looking behavior on the discs. Adult solvers frequently looked at the functioning disc and made more functioning than non-functioning disc patterns. In this experiment it is also examined whether specific looking behavior on the discs corresponds to verbally expressed gaze-contingent association learning.

Method

Participants. A sample of $N = 45$ (37 female) young adults participated in this study. As $n = 2$ participants had to be excluded because of calibration problems, data from $n = 43$ (35 female) participants remained. All participants were students of the Goethe-University, Frankfurt/Main, Germany. The age and scores on cognitive functioning measures are summarized in Table 3.

Table 3

Characteristics of the Participants

	M	*SD*
Age	23.09	5.67
Cognitive functioning measures		
FAIR raw	425.26	101.93
FAIR age standardized	6.47	1.80
Digit span raw	16.44	3.79
Digit span age standardized	11.77	2.77
Digit symbol raw	69.74	10.14
Digit symbol age standardized	13.58	2.43

All participants voluntarily[3] participated in the experiment and confirmed that they had normal or corrected-to-normal vision on the eye used for eye tracking. Participants partly received course credit for their participation.

Laboratory settings and eye tracker. The Department of Psychology moved in April 2013, and therefore the present study was conducted in the new developmental psychology

lab. Although the lab moved, care was taken to keep the laboratory settings the same. The same eye tracker as in Experiment 1 and 2 provided the eye tracking data.

Stimuli, gaze-contingent set-up, and materials. Two versions of the two discs GCLT were used. Version one was exactly the same as the task used in Experiment 2. In version two, the latency time between fixating the functioning disc and the appearance of the animal photograph was reduced to approximately 100 ms. No other changes to the task were made. A sample of $n = 13$ (9 female) young adults were tested in the short latency condition whereas $n = 30$ (26 female) young adults were tested in the long latency condition.

The same questionnaire as was used in Experiment 2 was used in this experiment.

To be able to exclude subjects from the sample in case of any indicators of pathological development, three different paper-and-pencil tests were administered. The paper-and-pencil tests consisted of two subtests (digit span and digit symbol tests) of the HAWIE-R (Hamburg-Wechsler Intelligence Scale for Adults, Tewes, 1991) to assess working memory and attention, respectively. As a third test, the FAIR (Frankfurt Attention Inventory, Moosbrugger & Oehlschlägel, 1996) was conducted which also assess attention. All three tests have been found to have high internal validity and adequate reliability (see Moosbrugger & Oehlschlägel, 1996; Tewes, 1991).

Procedure. After welcoming, explaining the study procedure, explaining the eye tracking procedure and obtaining written informed consent, participants immediately took part in the eye tracker study. Prior to testing, it was made sure that all participants understood what eye tracking was. However, they were not instructed about the gaze-contingent set-up. The eye tracker was adjusted and the calibration/validation procedure was conducted. After successful calibration and validation, the two discs GCLT experiment started. The experiment terminated and participants had to answer the questionnaire. The paper-and-pencil tests successively followed and then the session was finished by explaining the study's purpose and thanking the subjects for their participation. The total session took approximately 45-60 min.

Results

Effects of gender. Preliminary analyses of gender obtained no significant differences. Therefore, data was collapsed across this variable for subsequent analyses.

Questionnaire: Solvers and non-solvers. As in Experiment 2 participants were divided into groups of solvers and non-solvers based on the questionnaire.

Because analyses of side of functioning disc on percentage of solvers indicated no significant differences, data were collapsed across this variable for subsequent analyses.

Table 4, depicts the total number and percentage of solvers and non-solvers for the short and the long latency conditions. Pearson's chi-square analysis did not show a significant effect of latency condition (short vs. long) on (non-)solver, $X^2(1) = 0.05$, *ns*.

Table 4

The Number Respective Percentage of (Non-)solvers for the Short and the Long Latency Condition

	Latency condition	
	100 ms	450 ms
Solver	7 (54%)	15 (50%)
Non-solver	6 (46%)	15 (50%)

Looking behavior: Click interval data. Differences in click intervals between latency conditions and (non-)solvers were investigated. Mann-Whitney tests revealed that participants in the short latency condition (*Mdn* = 6603) had significantly shorter click intervals than participants in the long latency condition (*Mdn* = 10616), *U* = 47474.00, *z* = -6.54, *p* < .001, *r* = -.24. Moreover, solvers (*Mdn* = 7071.50) had significantly shorter click intervals than non-solvers (*Mdn* = 13675.50), *U* = 51682, *z* = -5.49, *p* < .001, *r* = -.20.

Looking behavior: Functioning and non-functioning disc pattern. As in Experiment 2, differences in the usage between the two discs are investigated with functioning and non-functioning disc patterns as the dependent variables.

A one-way ANOVA with latency condition, and (non-)solver as independent variables and functioning disc pattern as the dependent variable revealed main effects for the latency condition, $F(1, 39) = 4.40$, $p < .05$, $\eta_p^2 = .10$, and (non-)solver, $F(1, 39) = 5.35$, $p < .005$, $\eta_p^2 = .12$. Participants in the short latency condition (*M* = 20.00, *SD* = 9.19) made more functioning disc patterns than participants in the long latency condition (*M* = 14.23, *SD* = 7.78). Moreover, solvers (*M* = 18.82, *SD* = 8.34) made more functioning disc patterns than non-solvers (*M* = 13.00, *SD* = 7.89). No significant interaction effect between latency condition and (non-)solver was found.

A one-way ANOVA with latency condition and (non-)solver as independent variables and non-functioning disc pattern as the dependent variable did not reveal main effects for latency condition, $F(1, 39) = .23$, ns (short, $M = 7.08$, $SD = 3.28$; long, $M = 7.87$, $SD = 5.54$), or (non-)solver, $F(1, 39) = .00$, ns (solvers, $M = 7.50$, $SD = 3.38$; non-solvers, $M = 7.76$, $SD = 6.27$). No significant interaction effect between latency condition and (non-)solver was found.

A RM ANOVA with functioning and non-functioning disc patterns as repeated measure variables and latency condition as well as (non-)solver as independent variables revealed that more functioning ($M = 15.98$, $SD = 8.55$) than non-functioning ($M = 7.63$, $SD = 4.94$) disc patterns were made, $F(1, 39) = 37.77$, $p < .001$, $\eta_p^2 = .49$. Moreover, an interaction effect showed that this effect is significantly influenced by latency condition, $F(1, 39) = 4.15$, $p < .05$, $\eta_p^2 = .10$, and marginally by (non-)solver, $F(1, 39) = 3.76$, $p = .06$, $\eta_p^2 = .09$. Paired t-tests showed that participants in the short as well as in the long latency condition made more functioning than non-functioning disc patterns, $t(12) = 5.46$, $p < .001$, $r = .84$, and, $t(29) = 3.49$, $p < .005$, $r = .54$, respectively. However, this effect was stronger for the participants in the short than for the participants in the long latency condition. Paired t-tests also showed that solvers as well as non-solvers made more functioning than non-functioning disc pattern, $t(21) = 5.59$, $p < .001$, $r = .77$, and, $t(20) = 2.50$, $p < .05$, $r = .48$, respectively. However, this effect was stronger for the solvers than for the non-solvers.

Conclusion

In this experiment it was investigated whether the learning of the gaze-contingent association within the two discs GCLT by young adults is influenced by contiguity. Participants were tested either in a short (100 ms) or long (450 ms) latency condition. Overall it was found that learning to control the visual environment with looking behavior within the two discs GCLT is hard to learn for young adults. About half of the participating adults in both latency condtions could verbally express the gaze-contingent association and were therefore classified as solvers. This result is in line with the findings of Experiment 2.

The results of this experiment showed that the effect of contiguity on verbally assessed gaze-contingent association learning was not significant. The percentage of solvers did not differ among latency conditions. However, the results also demonstrated that contiguity influenced participants' looking behavior on the discs. It was found that participants in the short latency condition had shorter click intervals and made more functioning disc patterns than participants in the long latency condition. Moreover, participants in the short latency

condition made more functioning than non-functioning disc patterns whereas this effect was not found for the participants in the long latency condition. These findings show that contiguity influenced behaviorally assessed gaze-contingent association learning but that it did not influence verbally assessed gaze-contingent association learning. This result might indicate that contiguity influences unconscious learning of the gaze-contingent association within the two discs GCLT whereas it does not influence conscious learning of this gaze-contingent association.

In this experiment it was also examined whether specific looking behavior on the discs corresponds to verbally expressed gaze-contingent association learning. Similar as to what was found in Experiment 2, differences in looking behavior between solvers and non-solvers were found. It was found that solvers in comparison to non-solvers had shorter click intervals, made more functioning disc patterns, and made more functioning than non-functioning disc patterns. This finding suggests that looking behavior might also indicate that a gaze-contingent association is learned consciously. However as was also discussed in Experiment 2, it has to be kept in mind that looking behavior is an indirect measure of gaze-contingent association learning and that the only measure that provides certain evidence that subjects learned the gaze-contingent association consciously is their verbal expression of the association.

Experiment 4: Two Discs GCLT in Younger and Older Adulthood and the Influence of Prior Knowledge

Introduction

In this experiment the influence of *prior knowledge related cues* on learning the gaze-contingent association within the two discs GCLT by younger and older adults is tested. Thereby, it is first investigated whether there are differences in younger and older adults' gaze-contingent association learning within the two discs GCLT. Differences in younger and older adults' gaze-contingent association learning within the two discs GCLT are expected based on the theoretical thoughts that developmental differences in the learning processes that contribute to and in the perceptual processes, which are involved during operant conditioning learning, may exist (see Chapter 4, pages 42-47). Here, it is suggested that prior knowledge (increase in pragmatics) might be extremely important during older adults' operant conditioning learning. Because prior knowledge might be extremely important during older adults' operant conditioning learning and it could be that prior knowledge negatively influences gaze-contingent association learning within the two discs GCLT, as was discussed

in Experiment 2, it can be argued that gaze-contingent association learning within the two discs GCLT is very difficult for older adults. Therefore, it is hypothesized that gaze-contingent association learning within the two discs GCLT is more difficult for older than younger adults.

Second, it is examined whether prior knowledge related cues influence gaze-contingent association learning within the two discs GCLT. Prior knowledge might not only have a negative, but may also have a positive effect on operant conditioning learning. When prior knowledge is congruent with the association between response and effect that has to be learned, it might make it easier to learn a gaze-contingent association within the two discs GCLT (e.g., López & Shanks, 2008; Young, 1995). In this experiment manipulations in the experimental set-up of the two discs GCLT are made to investigate whether prior knowledge related cues can improve the learning of the gaze-contingent association. The prior knowledge related cues are implemented by changing the appearance of the discs. To start, the red discs were replaced by *green discs*. Adults can interpret red as a warning or "stop" color (e.g., Russo & Boor, 1993), and this color may even impair performance because of an acquired association to danger and failure (e.g., Elliot, Maier, Moller, Friedman, & Meinhardt, 2007), whereas green typically means good and stands for "go" in daily environments. In a second version, the red discs were replaced by *grey switches*. In this version, knowledge of how a switch normally looks is used as the grey switch resembles a certain kind of light switch. In daily life this light switch is associated with the effect of light, and it is assumed that this learned association supports the learning of the gaze-contingent association within the two discs GCLT. For this experiment it is hypothesized that the gaze-contingent association within the two discs GCLT will be better learned in a higher knowledge related version of the task. Moreover, as it is argued that prior knowledge is extremely important during older adults' gaze-contingent association learning it is suggested that older in comparison to younger adults will benefit more from these prior knowledge related cues.

Similar as to what was done in Experiment 2 and 3, adults' gaze-contingent association learning is measured behaviorally by assessing looking behavior and verbally by administering a questionnaire. Therefore, it is investigated whether age in adulthood and prior knowledge related cues influence adults' behaviorally assessed and verbally expressed gaze-contingent association learning. The results of Experiment 2 and 3 showed that a verbal expression of the gaze-contingent association corresponded to specific looking behavior on the discs. In this experiment it is also examined whether a specific looking behavior on the discs corresponds to verbally expressed gaze-contingent association learning.

Method

Participants. Additionally to the $n = 30$ (26 female) younger adults tested in the long latency condition of Experiment 3, a sample of $n = 42$ (31 female) younger and $n = 82$ (46 female) older adults were tested in the present experiment. Of these additionally tested participants $n = 2$ younger and $n = 1$ older adults had to be excluded because of calibration problems. Moreover, $n = 1$ older adult had to be excluded because of technical problems. Data from $n = 70$ (55 female) younger and $n = 80$ (45 female) older adults were used for the analyses made in the results section. As in Experiment 3, all younger adults were students at the Goethe-University, Frankfurt/Main, Germany. All older adults were enrolled in the University education program of the third age at the Goethe-University, Frankfurt/Main, Germany. The age and scores on cognitive functioning measures of all the younger and older participants are summarized in Table 5.

Table 5

Characteristics of the Younger and Older Participants

	Younger adults		Older adults	
	M	*SD*	*M*	*SD*
Age	22.24	5.24	68.08	5.06
Cognitive functioning measures				
FAIR raw	435.97	86.21	313.29	91.38
FAIR age standardized	6.76	1.65	5.84	1.91
Digit span raw	16.16	3.57	14.24	3.95
Digit span age standardized	11.51	2.55	11.38	2.87
Digit symbol raw	69.57	8.99	48.54	10.49
Digit symbol age standardized	13.36	2.15	14.53	2.61

All participants voluntarily[3] participated in the experiment and confirmed that they had normal or corrected-to-normal vision on the eye used for eye tracking. Younger adult participants partly received course credit for their participation.

Laboratory settings and eye tracker. Similar to Experiment 3, this experiment was conducted in the new developmental psychology lab. The same eye tracker as in Experiment 1, 2, and 3 provided the eye tracking data.

Stimuli, gaze-contingent set-up, materials, and procedure. The same procedure as in Experiment 3 was used. The only difference was that the two red discs were changed; namely, one version with green discs and another version with grey switches were administered (see Figure 16). As in Experiment 2 and 3, only one of the two discs functioned as a switch (counterbalanced position across participants). Although the discs were optically changed, the sizes, locations, and areas of interest were the same as in Experiment 2 and 3.
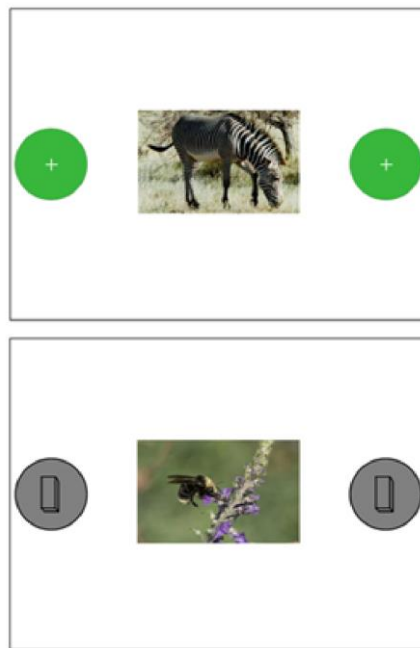
Figure 16. Examples of the experimental set-up with green discs or grey switches.

In Experiment 3 it was found that latency condition did not have an effect on verbally expressed gaze-contingent association learning, and therefore it was decided to test all participants in the long latency condition of the two discs GCLT. Table 6, gives an overview of the number of older and younger adults that participated in the red discs, green discs, and grey switches versions.

Table 6

The Number of Older and Younger Adults that Participated in the Red Discs, Green Discs, and Grey Switches Versions

	Disc version		
	Red discs	Green discs	Grey switches
Younger adults	$n = 30$ (26 female)	$n = 20$ (15 female)	$n = 20$ (14 female)
Older adults	$n = 40$ (23 female)	$n = 20$ (9 female)	$n = 20$ (13 female)

Results

Effects of gender. Preliminary analyses of gender obtained no significant differences. Therefore data was collapsed across this variable for subsequent analyses.

Cognitive functioning and age. Independent *t*-tests on the total sample of participants showed significant differences between age groups on the raw scores of the FAIR, $t(148) = 8.42$, $p < .001$, $r = .57$, digit span, $t(148) = 3.11$, $p = .001$, $r = .25$, and digit symbol, $t(148) = 13.09$, $p < .001$, $r = .73$, tests, see Table 5.

Independent *t*-tests on the total sample of participants showed that younger as opposed to older adults had higher age standardized scores on the FAIR, $t(148) = 3.14$, $p < .005$, $r = .25$. In contrast, older as opposed to younger adults had higher age standardized scores on the digit symbol test, $t(148) = -2.97$, $p < .005$, $r = .24$. Furthermore, younger and older adults did not show significant differences on the age standardized scores of the digit span test, $t(148) = .31$, *ns*, see Table 5.

Questionnaire: Solvers and non-solvers. A comparison between the percentage of solvers and non-solvers in the red discs, green discs and grey switches versions is made. As in Experiment 2 and 3, participants in the green discs and grey switches versions were divided into groups of solvers and non-solvers based on the questionnaire.

Preliminary analyses showed no effects of side of functioning disc on percentage of solvers, and therefore data was collapsed across this variable for subsequent analyses.

Table 7, gives an overview of the total number and percentage of solvers and non-solvers among the younger and older adults in the three different disc versions (red discs vs. green discs vs. grey switches). Pearson's chi-square analysis showed a significant association between age group and (non-)solver, $X^2(1) = 8.01$, $p = .005$, $\phi = .23$, in that there was a higher

percentage of younger than older solvers. Pearson's chi-square analysis did not show a significant effect of discs version on (non-)solver, $X^2(2) = 3.37$, *ns.*

Table 7

The Number Respective Percentage of (Non-)Solvers Among the Younger and Older Adults in the Red Discs, Green Discs, and Grey Switches Versions

	Disc version		
	Red discs	Green discs	Grey switches
Younger adults			
Solver	15 (50%)	9 (45%)	10 (50%)
Non-solver	15 (50%)	11 (55%)	10 (50%)
Older adults			
Solver	6 (15%)	6 (30%)	9 (45%)
Non-solver	34 (85%)	14 (70%)	11 (55%)

A three-way loglinear analysis showed that the three-way interaction between age group, disc version and (non-)solver was not significant, $X^2(1) = 3.56$, *ns.* Because it was hypothesized that the gaze-contingent association within the two discs GCLT will be better learned in a higher knowledge related version of the task and that older in comparison to younger adults will benefit more from these prior knowledge related cues, separate analysis between disc versions and age groups were realized, see Table 8.

Table 8

Pearson's Chi-square Analyses for the Associations Between the Different Comparisons of Disc Version and (Non-)solver for Both Age Groups

	Pearson's chi-square analyses
Younger adults	
Red discs - green discs	$X^2(1) = .12$, *ns*
Green discs - grey switches	$X^2(1) = .10$, *ns*
Red discs - grey switches	$X^2(1) = .00$, *ns*
Older adults	
Red discs - green discs	$X^2(1) = 1.88$, *ns*
Green discs - grey switches	$X^2(1) = .96$, *ns*
Red discs - grey switches	$X^2(1) = 6.40$, $p < 0.05$, $\phi = .33$

Looking behavior: Click interval data. Differences in click intervals between age groups, (non-)solvers, and disc versions were investigated. Mann-Whitney tests revealed that younger adults (*Mdn* = 9580) had significantly shorter click intervals than older adults (*Mdn* = 15415), $U = 565944$, $z = -3.91$, $p < .001$, $r = -.08$, and that solvers (*Mdn* = 7289) had significantly shorter click intervals than non-solvers (*Mdn* = 18356.50), $U = 385685.50$, $z = -15.60$, $p < .001$, $r = -.33$. Mann-Whitney tests also revealed that participants in the green discs version (*Mdn* = 7716) had significantly shorter click intervals than participants in the red discs version (*Mdn* = 13784), $U = 257490.50$, $z = -5.88$, $p < .001$, $r = -.15$. Moreover, it was found that the click intervals of the participants in the green discs version were significantly shorter than in the grey switches version (*Mdn* = 13326), $U = 187717.00$, $z = -4.71$, $p < .001$, $r = -.13$, whereas the click intervals of the participants in the grey switches version matched those of the participants in the red disc version, $U = 285042$, $z = -1.14$, *ns*.

Looking behavior: Functioning and non-functioning disc pattern. As in Experiment 2 and 3, differences in the usage between the two discs are investigated with the dependent variables functioning and non-functioning disc patterns. Figure 17, depicts the functioning and non-functioning disc patterns of the solvers and non-solvers in the younger and older age groups over the three different disc versions.
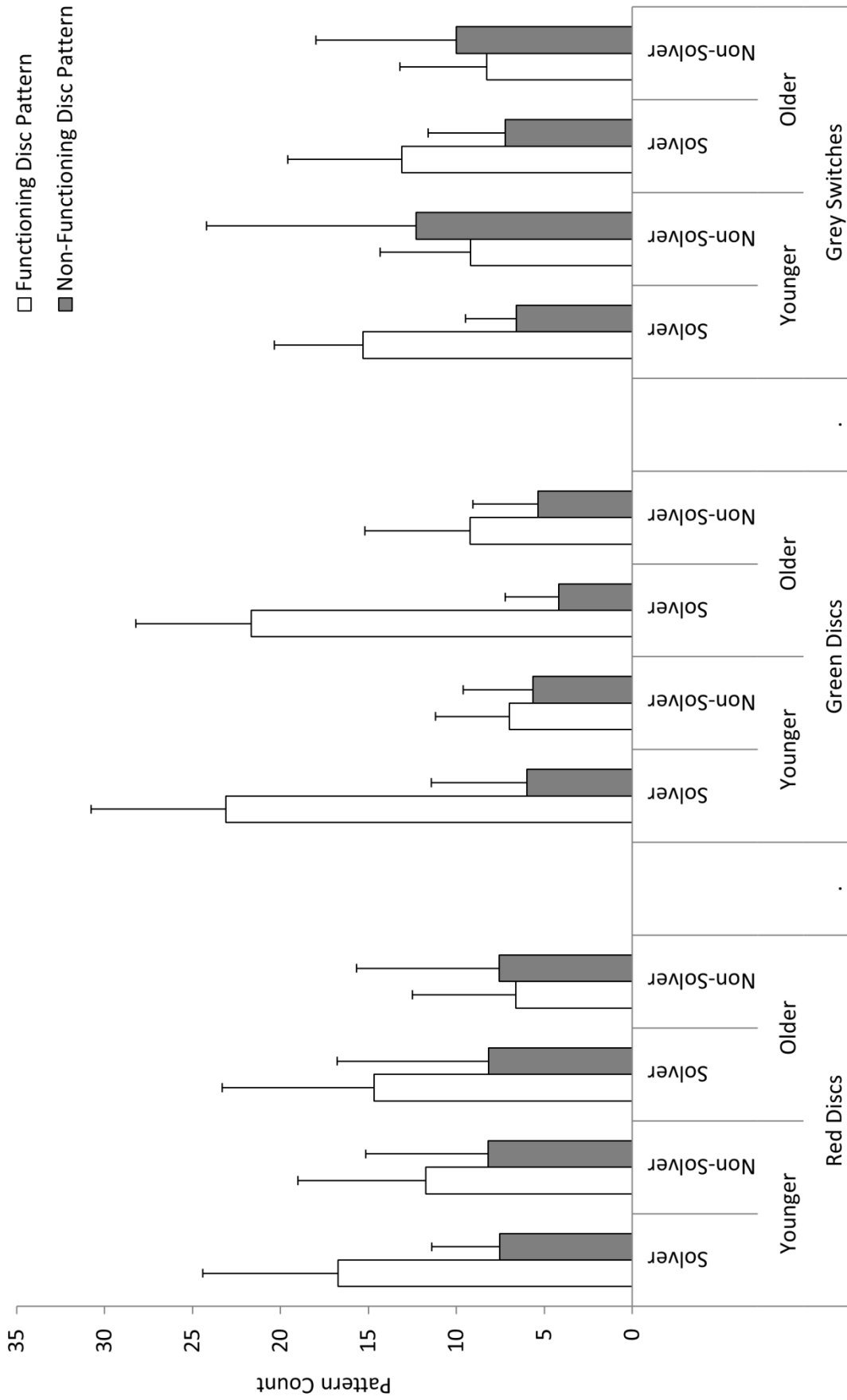
Figure 17. Functioning and non-functioning disc patterns (+ SD) of younger and older solvers and non-solvers over the three disc versions.

A three-way ANOVA with age group, disc version, and (non-)solver as independent variables and functioning disc pattern as the dependent variable revealed main effects disc version, $F(2, 138) = 3.67$, $p < .05$, $\eta_p^2 = .05$, and (non-)solver, $F(1, 138) = 59.55$, $p < .001$, $\eta_p^2 = .30$, see also Figure 17. Solvers ($M = 17.24$, $SD = 7.59$) made more functioning disc patterns than non-solvers ($M = 8.32$, $SD = 5.95$). Although a main effect for disc version was found, participants in the red discs version ($M = 10.57$, $SD = 7.90$) did not make more functioning disc patterns than participants in the green discs ($M = 13.60$, $SD = 9.18$) or grey switches version ($M = 11.35$, $SD = 5.95$), $t(108) = -1.82$, ns, and, $t(108) = -.54$, ns, respectively. Furthermore, no difference in functioning disc pattern between participants in the green discs and grey switches versions was found, $t(78) = 1.30$, ns.

This three-way ANOVA also showed an interaction effect between disc version and (non-)solver, $F(2, 138) = 5.59$, $p = .005$, $\eta_p^2 = .08$. Although this interaction effect was found, independent t-tests showed that solvers made more functioning disc patterns than non-solvers in the red discs (solvers, $M = 16.14$, $SD = 7.80$; non-solvers, $M = 8.18$, $SD = 6.71$), $t(68) = 4.33$, $p < .005$. $r = .46$, green discs (solvers, $M = 22.53$, $SD = 7.04$; non-solvers, $M = 8.24$, $SD = 5.30$), $t(38) = 7.29$, $p < .001$. $r = .76$, and grey switches (solvers, $M = 14.26$, $SD = 5.71$; non-solvers, $M = 8.71$, $SD = 4.93$), $t(38) = 3.30$, $p < .005$. $r = .47$, versions. However, the difference in functioning disc patterns between solvers and non-solvers seems to be smallest in the grey switches version.

A three-way ANOVA with age group, disc version, and (non-)solver as independent variables and non-functioning disc pattern as the dependent variable did not reveal main effects for age group, $F(1, 138) = .99$, ns (younger, $M = 7.73$, $SD = 6.52$; older, $M = 7.23$, $SD = 6.91$), disc version, $F(2, 138) = 3.01$, ns (red discs, $M = 7.70$, $SD = 7.07$; green discs, $M = 5.40$, $SD = 4.03$; grey switches, $M = 9.10$, $SD = 7.76$), and (non-)solver, $F(1, 138) = 3.76$, ns (solvers, $M = 6.33$, $SD = 3.94$; non-solvers, $M = 8.12$, $SD = 7.83$). Finally, no significant interaction effects between any of the independent variables were found.

A RM ANOVA with functioning and non-functioning disc patterns as repeated measure variables and age group, disc version, and (non-)solver as independent variables revealed that more functioning ($M = 11.59$, $SD = 7.86$) than non-functioning ($M = 7.46$, $SD = 6.71$) disc patterns were made, $F(1, 138) = 59.28$, $p < .001$, $\eta_p^2 = .30$. Moreover, interaction effects showed that this effect is influenced by disc version, $F(2, 138) = 7.42$, $p < .001$, $\eta_p^2 = .10$, and (non-)solver, $F(1, 138) = 51.66$, $p < .001$, $\eta_p^2 = .27$. Paired t-tests showed a significant more functioning than non-functioning disc patterns for the red discs

version, $t(69) = 2.41$, $p < .05$, $r = .28$, and green discs version, $t(39) = 4.98$, $p < .001$, $r = .62$, whereas no such effect was found for the grey switches version, $t(39) = 1.48$, *ns*. Furthermore, paired *t*-tests showed significant more functioning than non-functioning disc patterns for the solvers, $t(54) = 8.72$, $p < .001$, $r = .76$, whereas no such effect was found for non-solvers, $t(94) = .23$, *ns*.

Conclusion

In this experiment the influence of prior knowledge related cues on learning the gaze-contingent association within the two discs GCLT by younger and older adults was tested. Younger and older adults were either tested in a red discs, green disc, or grey switches version of the task.

The age standardized scores of the FAIR, digit symbol, and digit span test did not show systematic differences in younger and older adults cognitive functioning. However, differences between younger and older adults gaze-contingent association learning within the two discs GCLT were found. The results of the questionnaire revealed that the gaze-contingent association was easier to learn for younger than for older adults. This result is in line with the idea, that with increased age and prior knowledge it becomes harder to learn the gaze-contingent association within the two discs GCLT. The results also showed that age in adulthood corresponded to specific looking behavior on the discs. Younger adults had shorter click intervals than older adults. However, no difference in functioning and non-functioning disc pattern between age groups was found. In contrast to the differences found in younger and older adults' verbally assessed gaze-contingent association learning, the looking behavior data indicate that age in adulthood did not necessarily influence behaviorally assessed gaze-contingent association learning.

Overall, the effect of disc version on verbally assessed gaze-contingent association learning was not significant. The percentage of solvers did not differ among disc version of the task. However, behaviorally assessed gaze-contingent association learning showed that there are differences in looking behavior between disc versions. These data suggest different looking behavior in the grey switches version as opposed to the red or green discs versions. Participants in the grey switches version did not make more functioning than non-functioning disc patterns. It was also found that the difference in functioning disc pattern between solvers and non-solvers was the lowest in this version. Nevertheless, these differences in looking behavior on the grey switches compared to the red and the green discs do not necessarily indicate dissimilarities in learning a gaze-contingent association as looking behavior might

have been affected by the appearance of the switches. The switches constitute an additional feature (switch) which might have attracted visual attention to both of them.

Although it was found that the overall effect of disc version on verbally assessed gaze-contingent association learning was not significant. Additional analyses for the younger and older age groups separately provided a clearer description of the influence of prior knowledge related cues on verbally assessed gaze-contingent association learning. Table 7 shows that the percentage of younger solvers is stable between 45% and 55% over disc versions. In contrary, the percentage of older solvers varied from 15% in the red discs version to 30% in the green discs version and 45% in the grey switches version. Comparisons between discs versions provided significant evidence of a higher percentage of older solvers in the grey switches than in the red discs version of the task. These findings show that prior knowledge related cues did not make gaze-contingent association learning within the two discs GCLT easier for younger adults whereas it did make it easier for older adults. This result suggests that older adults' gaze-contingent association learning is more influenced by prior knowledge than younger adults' gaze-contingent association learning and is in line with the idea that prior knowledge plays an important role during operant conditioning learning in older adulthood (e.g., Baltes, 1987; Horn & Cattell, 1967).

Similar as to what was found in Experiment 2 and 3, the results showed that a verbal expression of gaze-contingent association learning corresponded to specific looking behavior on the discs. It was found that solvers in comparison to non-solvers had shorter click intervals and made more functioning disc patterns. Moreover, solvers made more functioning than non-functioning disc patterns whereas this effect was not found for non-solvers. Again, this finding suggests that looking behavior could also indicate that a gaze-contingent association is learned consciously.

Discussion

In this chapter, gaze-contingent association learning within the two discs GCLT was further investigated with adults. In Experiment 3 it was examined whether the learning of the gaze-contingent association within the two discs GCLT by younger adults is influenced by contiguity (situational information). In Experiment 4, the influence of prior knowledge related cues on the learning of the gaze-contingent association within the two discs GCLT by younger and older adults was tested.

Taken together, Experiment 3 and 4 showed that situational information as well as priori knowledge might influence adults' gaze-contingent association learning within the two

discs GCLT. It can be speculated that contiguity influences younger adults' unconscious learning of the gaze-contingent association whereas prior knowledge influences older adults' conscious learning of this association.

Consistent with the findings of Experiment 2, this chapter showed that learning to control the visual environment with looking behavior within the two discs GCLT is hard for adult participants. Moreover, developmental differences in gaze-contingent association learning between younger and older adults were found. It was found that conscious learning of the gaze-contingent association was harder for older than younger adults. Additionally, it was found that prior knowledge related cues improved older adults' conscious learning of the gaze-contingent association within the two discs GCLT whereas these cues did not improve younger adults' gaze-contingent association learning. Here, it can be speculated that increased prior knowledge made the learning of the gaze-contingent association within the two discs GCLT harder for older than for younger adults. However, this increased prior knowledge also made it easier for older adults to learn the gaze-contingent association within the two discs GCLT when prior knowledge related cues were presented.

Acknowledgements

Chapter 7

Giving Infants Control:
Passive Habituation-Dishabituation vs. One Disc GCLT Habituation-Dishabituation

Chapter 5 suggests that 6- and 8-month-old infants are able to learn the gaze-contingent association between specific looking behavior and a visual effect within the one and the two disc(s) GCLT. These results suggest that GCLT set-ups can be successfully used to put infants in control over their visual environment with looking behavior.

Such active control over the visual environment might influence infants' performances in experiments in which they have normally no control. A passive looking behavior task in which infants have normally no control is the *habituation-dishabituation task*. As has been explained in Chapter 3 (see page 23-24), the habituation-dishabituation procedure is often used to investigate infants' recognition and discrimination abilities. In this procedure infants are familiarized with a repeatedly presented stimulus (habituation phase) and when looking time drops to a predetermined level (i.e., 50% looking criterion) infants are thought to be habituated (e.g., Pascalis & de Haan, 2003; Rose et al. 2004). After being habituated, a dishabituation phase is given in which a new stimulus is presented and an increase in looking time to this new stimulus is expected (e.g., Kavšek, 2004). According to the comparator model habituation is caused by the construction of a mental representation of the repeatedly presented stimulus (*encoding*) and dishabituation occurs when a new stimulus is compared to this mental representation and an infant is able to discriminate between both of them (*discriminatory recognition memory*; e.g., Kavšek, 2004, 2013).

Within the present chapter it is investigated whether the one disc GCLT can be used to examine habituation-dishabituation learning in an active infant controlled manner. Moreover, it is examined whether such active control over the visual environment provided by the GCLT influences infants' habituation-dishabituation learning. Therefore, a comparison between a passive habituation-dishabituation experiment (Experiment 5) and actively controlled one disc GCLT habituation-dishabituation experiment (Experiment 6) is made.

Experiment 5 is a passive habituation-dishabituation experiment in which infants between 6 and 9 months of age are habituated to a female face. It is examined whether infants habituate to the repeatedly presented female face and dishabituate to a new face. Additionally, a more detailed investigation of infants' looking behavior on the female faces that are presented during habituation as well as dishabituation is made. A special focus is directed at

how individual differences in encoding speed (number of habituation trials) relate to individual differences in looking behavior during encoding as well as discrimination.

Experiment 6 is a one disc GCLT habituation-dishabituation experiment in which the same female faces as in Experiment 5 are implemented. In this experiment 6-month-old infants are tested. Firstly, it is examined whether infants habituate and dishabituate within the one disc GCLT set-up. Secondly, a comparison of 6-month-old infants' performances on the passive and the one disc GCLT habituation-dishabituation experiment is made.

Experiment 5: Passive Habituation-Dishabituation

Introduction

This experiment investigates infants' habituation and dishabituation on female faces within a passive habituation-dishabituation procedure. Female faces were used as stimuli because a considerable amount of research demonstrated that the human face constitutes a highly attractive visual stimulus for very young infants (see e.g., Maurer, 1985; Pascalis & Slater, 2003 for overviews). Some of the earliest studies on infants' face processing already revealed that newborn infants prefer faces over other comparably complex stimuli (e.g., Fantz, 1963; Goren, Sarty, & Wu, 1975). In addition, studies on face recognition and discrimination showed that infants recognize familiar faces and discriminate between different faces shortly after birth (e.g., Field, Cohen, Garcia, & Greenberg, 1984; Pascalis & de Schonen, 1994; Pascalis, de Schonen, Morton, Deruelle, & Fabre-Grenet, 1995).

Within this experiment, a special focus is directed at how *individual differences* in *encoding speed* (number of habituation trials) relate to individual differences in looking behavior during encoding as well as discrimination. Individual differences in encoding speed (measured by various indicators. i.e., looking time, number of habituation trials, and number of encoding trials) of visual stimuli have already been investigated. In general, it is thought that individual differences in encoding speed might relate to differences during discriminatory recognition memory. For example, it is suggested that infants with shorter looking times or less habituation trials during encoding (assumed to reflect faster stimulus encoding) perform better during an afterwards discriminatory recognition memory test than infants who need longer looking times or more habituation trials during encoding (e.g., for a review see Colombo & Mitchell, 1990; Rovee-Collier & Barr, 2010).

What might relate to the individual differences in encoding speed and discriminatory recognition memory are differences in looking behavior or in the processing of the stimuli (*processing strategies*). A number of studies applying individual differences analyses with

infants demonstrated that encoding speed might relate to processing strategies used during subsequent discrimination tasks. Studies that have used visual paired comparison designs with abstract objects (e.g., symmetrical and asymmetrical forms) as stimuli provide evidence that shorter looking infants have the tendency to process visual stimuli more globally (e.g., Colombo, Freeseman, Coldren, & Frick, 1995) whereas longer looking infants have the tendency to process visual stimuli more locally (e.g., Stoecker, Colombo, Frick, & Allen, 1998). However, a series of studies with faces as stimuli provided inconsistent results on how encoding speed and the processing of *global* and *local facial features* (which can be compared to configural and analytical face processing) relate (e.g., Orlian & Rose, 1997; Rose, Jankowski, & Feldman, 2002).

In their study, Orlian and Rose (1997) familiarized 6.5-month-old infants with a schematic face. The results of a subsequent discrimination phase showed that slow encoding infants (based on the number of trials during familiarization) discriminated between a new head contour with familiar facial features (eyes, nose, mouth, and brows) and a new head contour that had subtle changes in facial features (one or two novel facial features) but that fast encoding infants did not. The authors suggested that the differences found between fast and slow encoding infants might reflect differences in processing strategies in which fast encoding infants primarily relied on global structure, whereas slow encoding infants primarily relied on local features.

Interestingly, a study conducted by Rose et al. (2002) showed opposite results for older infants. In this study, 7- and 12-month-old infants were familiarized with a photograph of a natural face. The results of a subsequent discrimination task showed that only the fast encoding (based on the number of trials during familiarization) 12-month-old infants discriminated between a new and a fractured familiar face whereas the slow encoding infants could not. According to the authors, this finding indicates that the fast encoding 12-month-old infants recognized the fractured face and processed the local facial features whereas the slow encoding infants did not.

Taken together, these two studies provided inconsistent results on how encoding speed relates to facial processing strategies. Methodological differences between both studies (schematic faces vs. real faces; fractured stimuli vs. a new head contours with familiar facial features) might have partially caused these differences. However, more research is necessary to disentangle how encoding speed relates to facial processing strategies used.

Although Orlian and Rose (1997) and Rose et al. (2002) investigated whether encoding speed relates to infants' facial processing strategies, the looking behavior used during encoding as well as subsequent discrimination were not tested. In these studies no direct information about infants' looking behavior, and therefore no details about which internal facial features are looked at were obtained. Nowadays, advanced eye tracking techniques enable in-depth investigations of infants' looking behavior on faces and internal facial features during encoding as well as discrimination.

A few studies already used eye tracking to make detailed investigations of infants' looking behavior on faces and its internal facial features during encoding (e.g., Amso, Fitzgerald, Davidow, Gilhooly, & Tottenham, 2010; Gallay, Baudouin, Durand, Lemoine, & Lécuyer, 2006). Gallay et al. (2006), for example, investigated 4-month-old infants' looking behavior on faces during habituation and demonstrated that the *eyes* play a major role during stimulus encoding. Moreover, the results of this study indicated that the eyes are especially important at the beginning of face stimulus encoding. This observation is also discussed by Gliga and Csibra (2007), who from a theoretical point of view propose that it is the interest in the eyes that triggers infants' looking behavior towards faces.

In a study by Amso et al. (2010) it was found that individual differences in looking behavior on faces during encoding might relate to differences in subsequent face discrimination in some situations. In this study, 6- to 11-month-old infants were habituated to happy or fearful faces and discrimination was tested with a familiar face displaying a novel emotion (happy or fearful), a novel face with a novel emotion, and a novel face with the familiar emotion. The results indicated that only for infants habituated to fearful faces, a greater proportion of looking to the eyes as opposed to the mouth during habituation positively correlated with a longer looking time to the familiar face that had a happy emotion during subsequent discrimination. Therefore, these data suggest that in some specific situations the looking behavior on the eyes during encoding might relate to subsequent discrimination performances.

To sum up, there is ample evidence for a relation between encoding speed and processing strategies used during subsequent discrimination tasks. Although the face processing literature is somewhat unclear about this relationship (Orlian & Rose 1997; Rose et al., 2002), research with abstract objects as stimuli (e.g., Colombo et al., 1995) showed that faster encoding relates to more global processing whereas slower encoding relates to more local processing. However, these studies did not provide direct information

about infants' looking behavior. In these studies, no data on where infants looked when seeing the stimuli (which features) was obtained. Over the last decade a few eye tracking studies directly tested infants' looking behavior during the encoding of facial stimuli. Amso et al. (2010), for example, showed that looking behavior on faces during encoding relates to subsequent discrimination abilities. However, the direct relation between looking behavior and encoding speed has not yet been investigated in these studies. In the study by Amso et al. (2010) it might have been that the individual differences in looking behavior during encoding relate to differences in encoding speed. Therefore, the aim of the present experiment is to give a more detailed description on how differences in encoding speed (measured as number of habituation trials, habituation speed) relate to differences in looking behavior on faces during encoding as well as subsequent discrimination.

In this experiment, a passive habituation-dishabituation procedure with photographs of natural female faces is used. Infants are habituated to a repeatedly presented single face stimulus (habituation phase), and dishabituation is measured by comparing looking times to a new versus familiar face (dishabituation phase) using a fully automated eye tracking system. In the dishabituation phase the new face is followed by a familiar face. Moreover, the two faces used resemble each other in global structure. This global resemblance makes the two faces easier to discriminate over local feature information.

In the first place, the looking behavior on the face during habituation and dishabituation is investigated. In line with the comparator model (e.g., Colombo & Mitchell, 2009) a decrease in looking time to the repeatedly presented face is expected. Furthermore, it is expected that habituated infants would be able to discriminate between the new and familiar face.

Second, it is investigated whether there is a relation between habituation speed and looking behavior on the faces during habituation as well as dishabituation. Although it is usually thought that faster encoding infants show better discriminatory recognition memory than slower encoding infants (e.g., Colombo & Mitchell, 1990) it is also found that processing strategies might influence discriminatory abilities (e.g., Colombo et al., 1995). Differences in processing strategies between faster and slower encoding infants have been found in most of the previous research. These findings suggest that faster encoding infants primarily rely on global structure whereas slower encoding infants primarily rely on local features (e.g., Orlian & Rose, 1997). For the present experiment, it is assumed that a reliance on local features gives an advantage over a reliance on global structure as the later one was held constant.

Therefore, a better discriminatory recognition memory for slower as opposed to faster habituating infants is expected.

Third, it is investigated whether habituation speed relates to the looking behavior on the internal facial features (eyes, nose, and mouth) during habituation as well as dishabituation. The differences in processing strategies found by faster and slower encoding infants might be related to differences in looking behavior. Although Orlian and Rose (1997) and Rose et al. (2002) investigated whether encoding speed relates to infants facial processing strategies, the looking behavior used during encoding as well as subsequent discrimination were not tested previously. Here, it might be speculated that slower habituating infants who are supposed to use a more local processing strategy would look more to the internal facial features than faster habituating infants who are supposed to use a more global processing strategy. Therefore, it was decided to investigate whether slower habituating infants looked more at the internal facial features than faster habituating infants during habituation as well as dishabituation.

Furthermore, as it might have been that the individual differences in looking behavior during encoding found by Amso et al. (2010) relate to differences in habituation speed, it was decided to do an explorative analysis to find out whether habituation speed relates to specific looking behavior within the internal facial features during habituation as well as dishabituation.

Method

Participants. A sample of $N = 34$ (17 female) 6-month-old, $N = 10$ (4 female) 7.5-month-old, and $N = 30$ (16 female) 9-month-old infants visited the laboratory. As $n = 14$ 6-month-old, $n = 3$ 7.5-month-old, and $n = 6$ 9-month-old infants had to be excluded because of crying (6 m, $n = 5$; 7.5 m, $n = 1$; 9 m, $n = 1$), excessive movement (6 m, $n = 4$; 7.5 m, $n = 1$; 9 m, $n = 4$), and calibration problems (6 m, $n = 5$; 7.5 m, $n = 1$; 9 m, $n = 1$), data from $n = 20$ 6-month-old, $n = 7$ 7.5-month-old, and $n = 24$ 9-month-old infants remained. Out of $n = 20$ 6-month-old, $n = 7$ 7.5-month-old, and $n = 24$ 9-month-old infants finishing the study, $n = 17$ 6-month-old ($M = 187$ days, $SD = 3.20$ days; 9 female), $n = 5$ 7.5-month-old ($M = 230$ days, $SD = 4.76$ days; 3 female), and $n = 18$ 9-month-old ($M = 278$ days, $SD = 3.38$ days; 9 female) infants habituated according to the habituation criterion. All infants were healthy and had no known medical problems (birth week, birth weight, and APGAR-score were within standard values). None of the caregivers of the infants reported any known visual problems. As in Experiment 1 and 2, participants were recruited via informational flyers or locally distributed

advertisements in newspapers and family magazines. The caregivers of the participants' voluntarily[3] contacted us when they were interested in attending a study. All the infants that participated lived in the Frankfurt/Main metropolitan area and received a small toy as compensation.

Laboratory settings and eye tracker. Similar to Experiment 1 and 2, the experiment was conducted in the old developmental psychology lab of the Goethe-University in Frankfurt/Main, Germany. The same eye tracker as in Experiment 1, 2, 3, and 4 provided eye tracking data.

Stimuli and experimental set-up. The stimuli presented during the passive habituation-dishabituation experiment were colorful photographs of two different, Caucasian, smiling human female faces. At a viewing distance of 60 cm, the 528 x 692 pixel photographs subtended 16.5° visual angle horizontally x 22.9° visual angle vertically. The stimuli were presented at the center of the display screen against a gray background (see Figure 18).
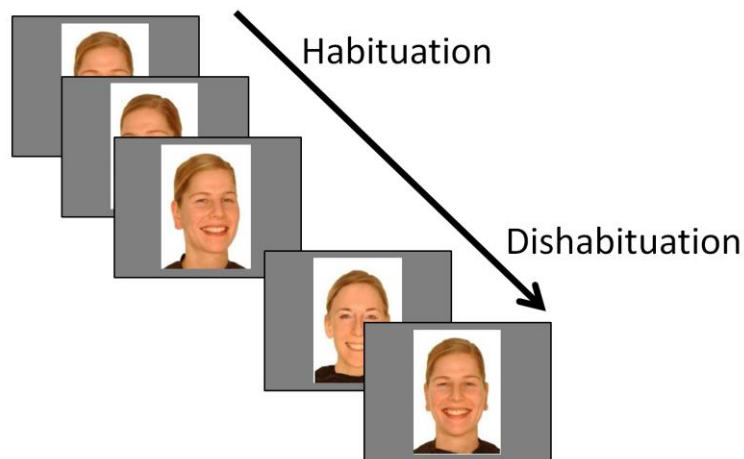
Figure 18. Example of stimulus set-up passive habituation-dishabituation.

The two face stimuli used resembled each other in global structure (i.e., both females have white skin, blond hair and wear black shirts). These two highly similar faces were used to make discrimination difficult and more local feature oriented. One of the faces was given during the habituation phase. To preclude that infants merely habituated to a specific perceptual stimulus, three different poses were used i.e., the frontal pose and two three-quarter poses (one turned 30° to the left and the other turned 30° to the right; see Figure 18). The three different poses used during the habituation phase were randomly presented, within

blocks of three trials. During the dishabituation phase, a frontal pose of the new face (second face) was followed by a frontal pose of the habituated, familiar face.

An infant-controlled habituation procedure (minimum number of trials = 6, maximum number of trials = 18, minimum look-away time = 2 s, maximum presentation time per trial = 40s, 50% criterion with the mean of the first three trials as the reference value) was used. After habituation, a dishabituation phase followed that consisted of two test trials in which a frontal pose of a new face followed by a frontal pose of the habituated, familiar face (see Figure 18). The dishabituation phase was also infant-controlled with a minimum look-away time of 2 s. Immediately after each trial, infant's attention was redirected to the monitor using an acoustic signal.

To measure infants' looking behavior on the faces and its internal facial features (eyes, nose, and mouth) rectangular areas of interest (AOIs) were manually defined (for an example see Figure 19). To measure the looking behavior on the face an AOI was centered on the whole picture (picture AOI). To measure the looking behavior on the internal facial features AOIs were centered on the eyes (eye AOI), the nose (nose AOI), and the mouth (mouth AOI). As a statistical measure, AOIs dwell time measuring the summation of all the fixations (in ms) within one trial and in a particular AOI was used.

Figure 19. Example of the AOIs (black lines) that were centered on the face (picture AOI), the eyes (eye AOI), the nose (nose AOI), and the mouth (mouth AOI).

As position of the different AOIs slightly differed between stimuli, AOIs were defined separately by stimulus and corrected in that position change did not influence AOI size. The exact size of each AOI is listed in the Appendix (Table A).
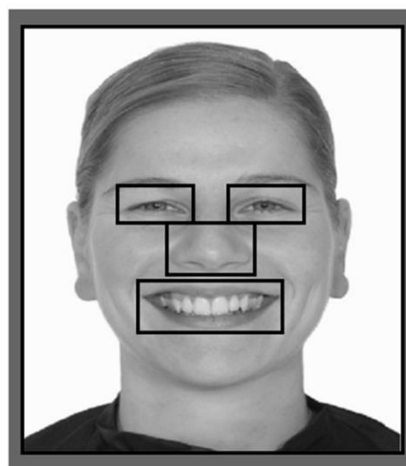
Procedure. After welcoming, explaining the study procedure, explaining the eye tracking procedure, and obtaining written informed consent, infants immediately took part in the eye tracker study. The eye tracker was adjusted and the calibration/validation procedure was conducted. After successful calibration and validation, the passive habituation-dishabituation eye tracking experiment started. The session took approximately 30 min and finished by thanking the infant and the caregiver for their participation and rewarding the infant with a little toy.

Results

For the habituation phase, statistical analyses were made with the mean of the first three and the last three faces looked at by each infant. First, statistical analyses for the habituation and dishabituation phase using the absolute dwell time (in ms) on the face stimuli (picture AOI) in general were conducted. Second, it was investigated whether habituation speed (number of habituation trials) relates to the absolute dwell time on the face stimuli presented during the habituation and the dishabituation phase. Third, the relation between habituation speed and relative (percentage of dwell time) looking behavior on the internal facial features was investigated. On the one hand, relative looking behavior on the internal facial features (internal facial features as a sum) as calculated by the sum of dwell time on the eye AOI, nose AOI, and mouth AOI divided by the total dwell time on the picture AOI were analyzed. On the other hand, relative looking behavior on the specific internal facial features (each internal facial feature separately) as calculated by the dwell time on each internal facial AOI (eye AOI, nose AOI, and mouth AOI) divided by the total dwell time on all internal facial AOIs were analyzed.

The analyzed data are based on a sample of the 40 infants who habituated according to the 50% looking time habituation criterion. As it is assumed that all infants who reach a predetermined level of habituation are at the same level of encoding (e.g., Oakes, 2010), it was decided to exclude the 11 infants who did not habituate, because it cannot be presumed that they reached the same level of encoding. The looking behavior data of the not habituated infants suggests that they did not show a steep decrease in mean dwell time on the repeatedly presented female face presented during the habituation phase. Their mean dwell time on the picture AOI of the first three faces was 6947 ms ($SD = 4119$) whereas the mean dwell time on

picture AOI of the last three faces was 5668 ms ($SD = 2660$). Furthermore, they did not show a higher mean dwell time on the picture AOI of the new ($M = 4306$, $SD = 3611$) as opposed to the familiar face ($M = 3719$, $SD = 3214$) presented during the dishabituation phase.

Effects of gender. Preliminary analyses of gender obtained no significant differences. Therefore, data was collapsed across this variable for subsequent analyses.

Effects of age. The infants that participated in this experiment were within a wide age range (between 6 and 9 month of age), and therefore it was decided to analyze whether age related to looking behavior on the faces presented during the habituation and the dishabituation phase. Preliminary analyses of age (as group; 6 m, 7.5 m, 9 m) on both the habituation and the dishabituation phase indicated no significant differences. Correlations indicated that infants' age in days did not relate to the absolute dwell time on the picture AOIs of the first three and the last three faces presented during the habituation phase. Moreover, infants' age in days did not relate to the absolute dwell time on the picture AOIs of the new and the familiar face presented during the dishabituation phase. Correlational analyses also revealed that age in days did not relate to infants' relative looking behavior on the internal facial features as a sum as well as on each internal facial feature separately during the habituation (first three and last three faces) and the dishabituation (new and familiar face) phase. Furthermore, age in days did also not correlate to the total habituation time looking at the habituation stimulus or to the number of habituation trials used. For subsequent analyses, data were collapsed across this variable.

Encoding speed: Habituation speed and total looking time on the faces during habituation. A correlational analysis showed a positive relation, $r = .53$, $p < .001$, between number of habituation trials (habituation speed) and total looking time on the faces during habituation (total dwell time on the picture AOI over all habituation trials). Infants who needed more trials to habituate tended to have a higher total dwell time on the picture AOI over all habituation trials and vice versa. However, additionally conducted analyses (partial correlations and hierarchical regression analyses) showed that the number of habituation trials was a better variable to describe the looking behavior of the infants on the faces and its internal facial features during habituation (first three and last three faces) as well as dishabituation (new and familiar face) than the total looking time on the faces during habituation. It was therefore decided to use the number of habituation trials as the main indicator for encoding speed.

Habituation and dishabituation on the face. To describe infants' looking behavior on the faces during the habituation phase a paired *t*-test was used to compare the mean dwell times on the first three and the last three faces presented. This *t*-test showed that infants' mean dwell time on the picture AOI of the first three faces ($M = 14675$, $SD = 6878$) was significantly higher than on the last three faces ($M = 5406$, $SD = 2863$), $t(39) = 12.74$, $p < .001$, $r = .90$.

In addition, a paired *t*-test was used to see whether infants could discriminate between the new and the familiar face presented during the dishabituation phase. This *t*-test confirmed that infants discriminated between the new and the familiar face during the dishabituation phase as infants' mean dwell time on the picture AOI of the new face ($M = 7488$, $SD = 6266$) was significantly higher than infants' mean dwell time on the picture AOI of the familiar face ($M = 5173$, $SD = 3614$), $t(39) = 2.08$, $p < .05$, $r = .32$.

Is there a linkage between habituation speed and looking behavior on the face? Correlations were calculated to explore if habituation speed is associated to the dwell time on the faces presented during the habituation and dishabituation phases. Separate correlations for the first three and the last three faces presented during the habituation phase as well as for the new and the familiar face presented during the dishabituation phase were conducted.

No significant relationships between the number of habituation trials and the dwell time on the picture AOI of the first three and last three faces were found, $r = -.17$, *ns*, and, $r = -.10$, *ns*, respectively. To sum up, habituation speed did not relate to infants' looking behavior on the faces presented during the habituation phase. Although it was found that habituation speed related to the total dwell time on the picture AOI over all habituation trials, no such effect for the first three or the last three habituation trials was found.

A significant relationship between the number of habituation trials and the dwell time on the picture AOI of the new face was found, $r = .48$, $p < .005$. Slower habituating infants tended to have a higher mean dwell time on the picture AOI of the new face than faster habituating infants. No such effect was found for the familiar face, $r = -.24$, *ns*. To summarize, habituation speed related to infants' looking behavior on the new face presented during the dishabituation phase whereas it did not relate to the looking behavior on the familiar face.

To further analyze the relation between habituation speed and looking behavior on the picture AOI of the faces presented during the dishabituation phase, infants were divided in two groups via median split, i.e. a median of 8 habituation trials to reach habituation criterion

resulted in two groups ($n = 20$ each) of fast ($M = 6.05$ trials, $SD = .22$) and slow ($M = 10.08$ trials, $SD = 2.22$) habituating infants.

A RM ANOVA with dishabituation (new vs. familiar face) as the repeated measure variable and habituation speed (fast vs. slow) as the independent variable revealed a main effect for dishabituation, $F(1, 38) = 4.63$, $p < .05$, $\eta_p^2 = .11$. This main effect for dishabituation shows that infants' mean dwell time on the picture AOI of the faces presented during the dishabituation phase was affected by type of face (new vs. familiar) presented. In accordance with the significant paired t-test for the dishabituation phase, this main effect shows that infants' mean dwell time on the picture AOI of the new face ($M = 7488$, $SD = 6266$) was higher that infants' mean dwell time on the picture AOI of the familiar face ($M = 5173$, $SD = 3614$). Furthermore, a marginal interaction effect between dishabituation and habituation speed, $F(1, 38) = 3.72$, $p = .061$, $\eta_p^2 = .09$, was found.

Post hoc analyses for the fast and the slow habituating infants showed a significant decrease in mean dwell time on the picture AOI from the new ($M = 8629$, $SD = 7753$) to the familiar face ($M = 4240$, $SD = 3105$) for the slow habituating infants, $t(19) = 2.53$, $p < .05$, $r = .50$. This effect was not found for the fast habituating infants (new, $M = 6347$, $SD = 4212$; familiar, $M = 6106$, $SD = 916$), $t(19) = .19$, *ns*.

Is there a linkage between habituation speed and looking behavior on internal facial features? The relative looking behavior on the internal facial features as a sum were examined to give some more insight on whether the infants used the internal facial features during habituation as well as dishabituation. Infants' mean percentage of dwell time on the internal facial features as a sum was 58% on the first three faces and 47% on the last three faces presented during the habituation phase. Furthermore, infants' mean percentage of dwell time on the internal facial features as a sum was 46% and 57% on the new and familiar face presented during the dishabituation phase, respectively.

Correlations were calculated to explore whether slower habituating infants had a higher percentage of dwell time on the internal facial features as a sum than faster habituating infants. Separate correlations for the first three and the last three faces presented during the habituation phase and the new and familiar face presented during the dishabituation phase were conducted and the results of these correlations are summarized in Table 9.

Table 9

Correlational Analyses for the Relation between Habituation Speed and Relative Dwell Times on the Internal Facial Features as a Sum for the First Three and the Last Three Faces Presented during the Habituation Phase as well as the New and the Familiar Face Presented during the Dishabituation Phase

	Habituation phase		Dishabituation phase	
	First three faces	Last three faces	New face	Familiar face
Internal facial features as a sum	-.15 (-.44, .17)	-.02 (-.33, .29)	.12 (-.20, .42)	.01 (-.30, .32)

Note. 95% confidence intervals are shown in brackets.

To summarize, no significant relationships between the number of habituation trials and the percentage of dwell time on the internal facial features as a sum for the first three and the last three faces presented during the habituation phase, as well as the new and the familiar face presented during the dishabituation phase, were found.

Is there a linkage between habituation speed and looking behavior on specific internal facial features? The relative looking behavior on each internal facial feature separately, were examined to give some more insight on which internal facial features were primarily looked at during habituation as well as dishabituation. Figure 20 depicts the distribution of the percentage of dwell time on the eyes, nose, and mouth on the first three and the last three faces presented during the habituation phase as well as the new and the familiar face presented during the dishabituation phase.

Figure 20. The distribution of the percentage of dwell time on the eye AOI, nose AOI, and mouth AOI of the first three and the last three faces presented during the habituation phase as well as the new and the familiar face presented during the dishabituation phase.

Note. $n = 40$ for the first three faces, last three faces, and familiar face. $n = 37$ for the new face. Three infants were excluded from the analyses for the new face, although these infants looked at the picture AOI of the new face they did not look at the internal facial features. The AOIs where a slower as opposed to faster habituation speed relates to a higher percentage of dwell time are indicated by +. The AOI where a faster as opposed to slower habituation speed relates to a higher percentage of dwell time is indicated by a -.

Correlations were calculated to explore if habituation speed is associated to the relative dwell times on each internal facial feature separately (eyes, nose, and mouth). Separate correlations for the first three and the last three faces presented during the habituation phase as well as the new and the familiar face presented during the dishabituation phase were conducted. The results of these correlations are summarized in Table 10.

Table 10

Correlational Analyses for the Relation between Habituation Speed and Relative Dwell Times on Each Internal Facial Feature Separately for the First Three and the Last Three Faces Presented during the Habituation Phase as well as the New and the Familiar Face Presented during the Dishabituation Phase
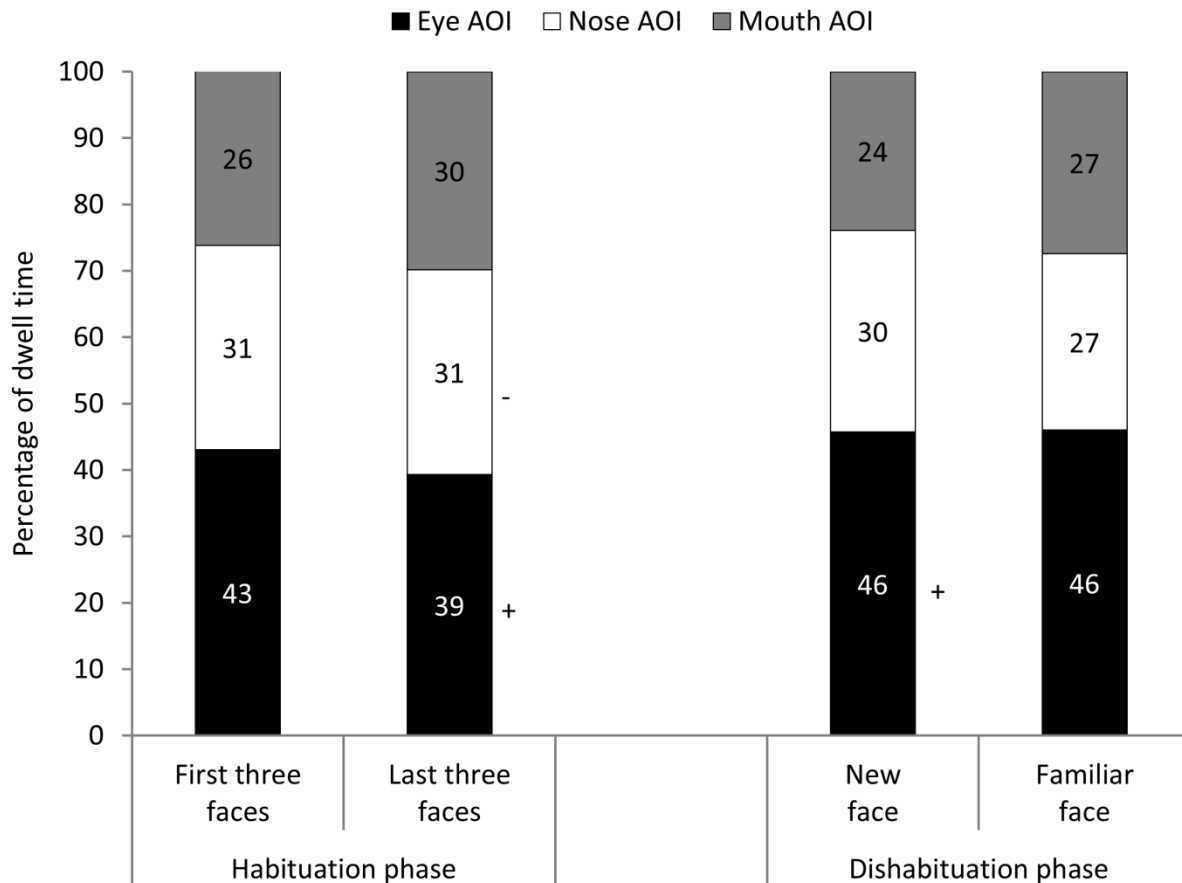
	Habituation phase		Dishabituation phase	
	First three faces	Last three faces	New face	Familiar face
Eyes	.21	.36[*]	.34[*]	-.02
	(-.11, .49)	(.06, .60)	(.02, .60)	(-.34, .31)
Nose	-.12	-.32[*]	-.13	.20
	(-.42, .20)	(-.57, -.01)	(-.44, .20)	(-.12, .48)
Mouth	-.19[*]	-.10	-.25	-.17
	(-.47, .13)	(-.40, .22)	(-.53, .08)	(-.46, .15)

Note. $n = 40$ for the first three faces, last three faces, and familiar face. $n = 37$ for the new face. Three infants were excluded from the analyses for the new face, although these infants looked at the picture AOI of the new face they did not look at the internal facial features. 95% confidence intervals are shown in brackets.

[*]$p < .05$.

When looking at the distribution of the percentage of dwell time on the eyes, nose, and mouth, it was found that slower habituating infants tended to have a higher percentage of dwell time on the eyes of the last three faces presented during the habituation phase as well as the new face presented during the dishabituation phase. Moreover, it was found that faster habituating infants tended to have a higher percentage of dwell time on the nose of the last three faces presented during the habituation phase.

Figure 21 gives an impression of how fast and slow habituating infants looked at the new and the familiar face presented during the dishabituation phase. The data displayed in Figure 21 is based on the median split on the number of habituation trials and illustrates that slower habituating infants tended to look more on the eyes of the new face as compared to faster habituating infants. No such difference can be seen regarding the familiar face.
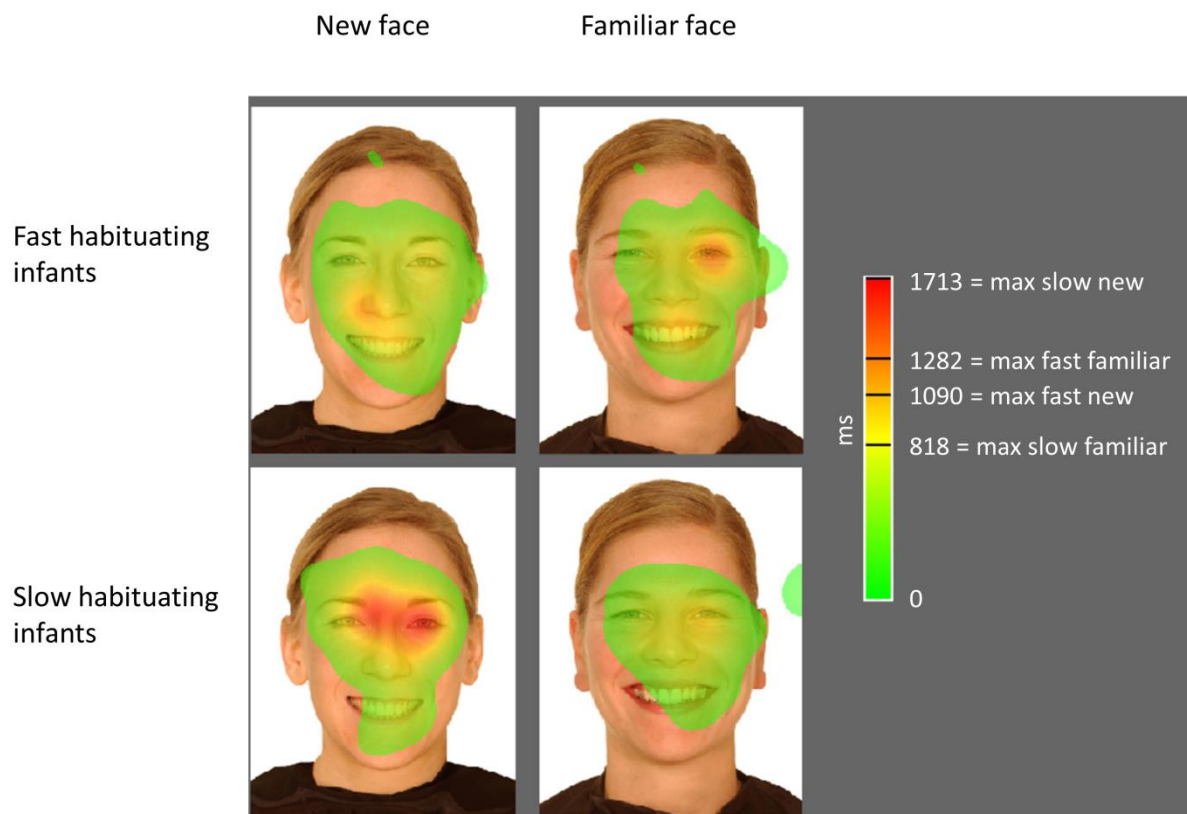
Figure 21. Example of fast and slow habituating infants' looking behavior (fixation durations) on the new and the familiar face presented during the dishabituation phase.

Note. The frequently fixated areas are painted in red whereas the less-fixated areas are painted in green or have no color at all. In order to compare the four heatmaps, the same heatmap settings were used for all four of them. The maximum fixation duration of the fast and slow habituating infants on the new and familiar face are shown along the color scale. The highest maximum fixation duration of 1713 ms was reached by the slow habituating infants on the new face. These heatmaps serve as an illustration of infants looking behavior and exemplifies the effects found in the correlation analyses for the total group of infants. This heatmap was created following the guidelines of Bojko (2009).

Conclusion

In this experiment, 6- to 9-month-old infants' looking behavior on faces that were presented during a passive habituation-dishabituation procedure was analyzed. A special focus was directed at how differences in habituation speed relate to differences in looking behavior during encoding as well as discrimination.

First, the results of this experiment demonstrated that infants were able to habituate to the repeatedly presented stimulus as looking time on the face decreased from the first three to

the last three faces presented during the habituation phase. Furthermore, infants showed more looking time on the new than on the familiar face during the dishabituation phase. These results are in line with previous studies (e.g., Field et al., 1984; Pascalis & de Schonen, 1994; Pascalis et al., 1995) as well as the comparator model (e.g., Colombo & Mitchell, 2009) and demonstrate that the habituated infants encoded the familiar face and were able to discriminate between the new and familiar face.

Second, it was investigated whether there is a relation between habituation speed and looking behavior on the face (picture AOI) during habituation as well as dishabituation. The results of the habituation phase showed that there was no relation between habituation speed and looking behavior on the first three and last three faces when analyzing the picture AOI. However, the results of the dishabituation phase showed that there is a relation between habituation speed and looking behavior on the picture AOI during discrimination. As expected, it was found that slower habituating infants could better discriminate between the new and familiar face than faster habituating infants.

In the habituation literature it is thought that the number of habituation trials indicates the ability to encode a stimulus into memory, with a smaller number of habituation trials indicating quicker encoding than a larger number of habituation trials (Kavšek, 2004). Usually it is thought that faster encoding infants show better discriminatory recognition memory than slower encoding infants (e.g., Colombo & Mitchell, 1990; Rovee-Collier & Barr, 2010), however, there is also evidence that processing strategies might influence discriminatory abilities (e.g., Colombo et al., 1995). For example, Orlian and Rose (1997) found that slower encoding infants were better at discriminating between schematic faces with familiar facial features and faces with subtle changes than faster encoding infants. The authors suggested that faster encoding infants primarily relied on global structure whereas slower encoding infants primarily relied on local features. Furthermore Orlian and Rose (1997) put forward that a more local processing strategy compared to a more global processing strategy might actually give a performance advantage in specific situations that ask for more thorough processing during encoding. Presumably, in this experiment, a more local processing strategy gave advantage over a more global processing strategy as local information was necessary to discriminate between the highly similar familiar and new face presented during the dishabituation phase.

Third, it was examined whether habituation speed relates to the looking behavior on the internal facial features during habituation as well as dishabituation. Although it might be

speculated that slower habituating infants who are supposed to use a more local processing strategy (e.g., Orlian & Rose, 1997; Stoecker et al., 1998) would look more to the internal facial features than faster habituating infants who are supposed to use a more global processing strategy, the present experiment does not confirm this idea when analyzing infants' looking behavior on all internal facial features (eyes, nose, and mouth). No relation between habituation speed and looking behavior on the internal facial features as a sum of the first three and last three faces presented during the habituation phase as well as the faces presented during dishabituation were found. However, a relation between habituation speed and specific looking behavior within these facial features was found. The results of this experiment show that slower as opposed to faster habituating infants tended to have a higher interest in the eyes during habituation as well as dishabituation. This finding suggests that slower as opposed to faster habituating infants do not necessarily use looking behavior which is more directed at all local features but that they used looking behavior that was more directed at one specific internal facial feature which can be considered as a specific local processing strategy.

Moreover, a better discrimination of the new and familiar face by the slower than faster habituating infants was found. In combination, the results of a better discrimination and different looking behavior within the facial features for slower as opposed to faster habituating infants, indicates that the better discrimination of the new and familiar face by the slower than faster habituating infants might be related to their sustained interest in the eyes. Therefore, this experiment suggests that slower as opposed to faster habituating infants used looking behavior that was more directed at one specific internal facial feature which in this case might have led to a benefit during discrimination.

Orlian and Rose (1997) suggested that slower as compared to faster encoding infants might have a performance advantage in specific situations that ask for more thorough processing during encoding. Furthermore, Amso et al. (2010) found that individual differences in looking behavior on faces during encoding relate to differences in face discrimination in some situations but not in others. In this experiment, looking behavior and habituation speed were linked and it was found that a slower as opposed to faster habituation speed relates to specific looking behavior on the eyes and a benefit during discrimination of the new and familiar face. The present experiment might have offered an optimal situation where an increased interest in important social cues indicated by a more thorough processing of the eyes by slower as compared to faster habituating infants led to better discrimination.

This experiment underlines a special role for the eyes during encoding and discrimination of face stimuli, which was also suggested by Gliga and Csibra (2007). Furthermore, this finding is in line with eye tracking studies showing that the eye region is essentially important for face processing (e.g., Oakes & Ellis, 2013; Gallay et al., 2006). Therefore, the present experiment demonstrates that the eyes are not only important because they provide important social cue information but that they are also important for encoding as well as discrimination of face stimuli.

Taken together, this experiment showed that infants habituated and dishabituated within the passive habituation-dishabituation procedure. Moreover, this is the first experiment that directly linked individual differences in habituation speed to individual differences in looking behavior on faces during habituation as well as dishabituation. The results suggest that habituation speed relates to specific looking behavior within the facial features during encoding as well as discrimination. Furthermore, a slower habituation speed with specific looking behavior on the eyes might give an advantage for discrimination in some specific situations.

Experiment 6: One Disc GCLT Habituation-Dishabituation

Introduction

The one disc GCLT, offers the opportunity to make a habituation-dishabituation procedure active in that infants can look at the disc in order to trigger the next habituation or dishabituation stimulus. Within this experiment it is investigated whether infants still habituate and dishabituate when such active control over the visual environment is provided.

Infants habituation and dishabituation within an operant conditioning task has already been investigated in various studies (e.g., Rovee-Collier & Gekoski, 1979; Weir, Soule, Bacchus, Rael, & Schneider, 2000; Weir, Toland, King, Martin, 2005). For example, Weir et al. (2000) let 5- to 13-month-old infants touch a canister in order to cause light-sound stimulations. Infants were tested in four groups that had different experiences prior to the operant conditioning task. One group of infants saw a caregiver touch the canister that resulted in contingent light-sound stimulations. A second group of infants saw a caregiver touch the canister that resulted in non-contingent light-sound stimulations. The third group of infants saw a caregiver who did not touch the canister but still light-sound events were presented. The fourth and last group did not have any pre-experience with the canister before the operant conditioning task started. The results of this study showed patterns of habituation within the operant conditioning session of all groups of infants. The infants showed an

initially high response level followed by a long-term decrease. In their discussion Weir et al. (2000) argue that the infants might have habituated to the light-sound stimulation, to the association itself, or to the visual and tactile elements of the touch. They discuss that habituation to the light-sound stimulation is the most likely explanation of the habituation pattern found as infants without pre-experiences showed a later decrease in responding which corresponds to habituation. In short, this study suggests that infants habituate to a light-sound stimulation that is presented within an operant conditioning task. Therefore, this study shows that habituation also takes place within operant conditioning tasks.

Dishabituation has also been found within operant conditioning tasks. When a response within an operant conditioning task produces the same effect (same stimulus) over and over again a subject will habituate. However, when a new effect (new stimulus) is introduced conditioning responding is reinstalled (Rovee-Collier & Gekoski, 1979).

In this experiment 6-month-old infants' habituation and dishabituation within the one disc GCLT is examined. The same female faces that were used in Experiment 5 are implemented in the one disc GCLT. Consistent with the findings of Weir et al. (2000, 2005) it is expected that infants habituate to the face presented during habituation. In line with the habituation-dishabituation literature (e.g., Kavšek, 2004, 2013; Rovee-Collier & Gekoski, 1979) it is also expected that the habituated infants dishabituate during the dishabituation phase. Finally, a comparison of 6-month-old infants' performances on the passive and one disc GCLT habituation-dishabituation experiment is made. It is investigated whether infants' looking behavior on the faces presented during habituation and dishabituation differs between both experiments.

Method

Participants. A sample of $N = 38$ (23 female) 6-month-old infants visited the laboratory. As $n = 17$ infants had to be excluded because of crying ($n = 5$), excessive movement ($n = 11$), and calibration problems ($n = 1$), data from $n = 21$ infants remained. Out of the $n = 21$ infants finishing the study, $n = 18$ ($M = 187$ days, $SD = 3.84$ days; 11 female) habituated according to the habituation criterion. All infants were healthy and had no known medical problems (birth week, birth weight, and APGAR-score were within standard values). None of the caregivers of the infants reported any known visual problems. As in Experiment 1, 2, and 5, participants were recruited via informational flyers or locally distributed advertisements in newspapers and family magazines. The caregivers of the participants' voluntarily[3] contacted us when they were interested in attending a study. All the infants that

participated lived in the Frankfurt/Main metropolitan area and received a small toy as compensation.

Laboratory settings and eye tracker. Some of the infants were tested in the old and some of the infants were tested in the new developmental psychology lab of the Goethe-University in Frankfurt/Main, Germany. The same eye tracker as in Experiment 1, 2, 3, 4, and 5 provided the eye tracking data.

Stimuli and gaze-contingent set-up. Before the one disc GCLT habituation-dishabituation part of the study started, a training phase was administered. The materials and experimental set-up used during the training phase are exactly the same as in Experiment 1. Immediately, after the training phase the one disc GCLT habituation-dishabituation experiment was administered (see Figure 22).
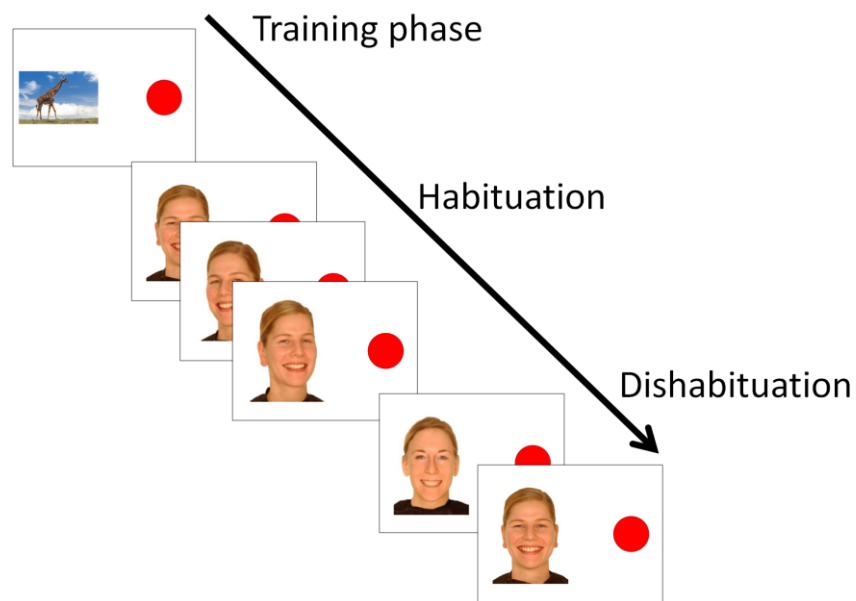
Figure 22. Example of stimulus set-up one disc GCLT habituation-dishabituation.

The one disc GCLT habituation-dishabituation set-up consists of a red disc at the right side and a stimulus presentation frame at the left side of the computer screen. At a viewing distance of 60 cm, the 200 x 200 pixel red disc subtended 6.1° visual angle horizontally x 6.7° visual angle vertically (middle coordinates in pixels: x = 850, y = 384) and the 450 x 552 pixel stimulus presentation frame (left-top coordinates in pixel: x = 80, y = 109) subtended 13.0° visual angle horizontally x 17.9° visual angle vertically. The stimuli presented in the

stimulus presentation frame were the same colorful photographs of two different, Caucasian, smiling human female faces as in Experiment 5. However, the red disc that was simultaneously presented with the female faces caused space constrains, and therefore the sizes of the female faces were somewhat smaller in the one disc GCLT habituation-dishabituation experiment than in the passive habituation-dishabituation experiment. The stimuli were presented against a white background (see Figure 22). Areas of interest (AOI) were manually defined to exactly match the red disc and the animal photographs or faces that were presented in the stimulus presentation frame. As a statistical measure, AOIs dwell time measuring the summation of all the fixations (in ms) within one trial and in a particular AOI was used.

By fixating the red disc at the right side of the display screen infants triggered the appearance of a face stimulus in the predefined stimulus presentation frame located at the left side of the display screen. As in Experiment 5, only one of the two faces was presented during the habituation phase whereas the other one was presented during the dishabituation phase. To preclude that infants just habituated to a specific perceptual stimulus, three different poses were used i.e., the frontal pose and two three-quarter poses (one turned 30° to the left and the other turned 30° to the right; see Figure 22). The three different poses used during the habituation phase were randomly presented, within blocks of three trials. During the dishabituation phase, a frontal pose of the new face was followed by a frontal pose of the habituated, familiar face (see Figure 22).

As in Experiment 5, a 50% habituation criterion (minimum number of trials = 6, maximum number of trials = 18, with mean of first three trials as reference value) was used. The dishabituation phase was also gaze-contingent, i.e., a fixation on the red disc triggered the appearance of a face stimulus. Immediately after each trial, infant's attention was redirected to the monitor using an acoustic signal.

Procedure. After welcoming, explaining the study procedure, explaining the eye tracking procedure, and obtaining written informed consent, infants immediately took part in the eye tracker study. The eye tracker was adjusted and the calibration/validation procedure was conducted. After successful calibration and validation, the one disc GCLT training phase started. Immediately, after the training phase the one disc GCLT habituation-dishabituation experiment was administered. The session took approximately 30 min and finished by thanking the infant and caregiver for their participation and rewarding the infant with a little toy.

Results

All infants that did not habituate according to the 50% criterion ($n = 3$) were excluded because it could not be assumed that these infants were at the same level of encoding (e.g., Oakes, 2010). As in Experiment 5, statistical analyses for the habituation phase were made with the mean of the first three and last three faces looked at by each infant. The looking behavior data of the not habituated infants suggests that they did not show a steep decrease in mean dwell time to the repeatedly presented female face presented during the habituation phase. Their mean dwell time on the picture AOI of the first three faces was 3083 ms ($SD = 1592$) whereas the mean dwell time on the picture AOI of the last three faces was 2477 ms ($SD = 1525$). However, they showed a higher mean dwell time to the picture AOI of the new ($M = 19302$, $SD = 9051$) as opposed to the familiar face ($M = 2482$, $SD = 2550$) presented during the dishabituation phase.

Effects of gender. Preliminary analyses of gender obtained no significant differences. Therefore, data was collapsed across this variable for subsequent analyses.

Training phase. Because of computer problems the training phase data of one of the infants could not be used, and therefore $n = 17$ infants for the training phase data.

First, 6-month-old infants' looking behavior on the disc that triggers new stimuli was analyzed. Similar as to what was found in Experiment 1, it was shown that within a minute infants' frequently looked at the disc that resulted in the appearance of a new animal photograph ($M = 18.29$, $SD = 5.60$).

Second, infants' average fixation duration on the disc and the animal photographs that were only presented for 1.5 s were analyzed. A paired *t*-test showed that infants' average fixation duration on the animal photograph ($M = 609.42$, $SD = 170.97$) was longer than on the disc ($M = 442.99$, $SD = 124.77$), $t(16) = -3.85$, $p < .001$, $r = .69$.

Third, infants' expectancies of the new upcoming animal photographs were investigated. According to the 200 ms criterion infants' average percentage of anticipations was 41% ($SD = 18.64$).

No relations between the training phase and looking behavior during the one disc GCLT habituation-dishabituation experiment were found. Therefore, the one disc GCLT habituation-dishabituation experiment is separately discussed.

Habituation and dishabituation on the face. To describe infants' looking behavior on the faces during the habituation phase a paired *t*-test was used to compare the mean dwell

times on the first three and the last three faces presented. This *t*-test showed that infants mean dwell time on the first three faces ($M = 17866$, $SD = 15924$) was significantly higher than on the last three faces ($M = 4315$, $SD = 2861$), $t(17) = 3.98$, $p < .001$, $r = .51$.

In addition, a paired *t*-test was used to see whether infants could discriminate between the new and the familiar face presented during the dishabituation phase. This *t*-test showed that infants could not discriminate between the new and the familiar face as infants' mean dwell time on the new face ($M = 5916$, $SD = 8354$) did not differ from infants' mean dwell time on the familiar face ($M = 7208$, $SD = 10153$), $t(17) = -.62$, *ns*.

For this experiment no relations between habituation speed and looking behavior on the faces (picture AOI) during the habituation or dishabituation phase were found. In this experiment smaller faces were used than in Experiment 5. These smaller faces and their smaller internal facial features made analyses of a relation between habituation speed and looking behavior on internal facial features impossible.

Comparison of passive and one disc GCLT habituation-dishabituation. A comparison between passive and one disc GCLT habituation-dishabituation with 6-month-old infants is made. The 6-month-old-infants tested in the present experiment are compared to the $n = 17$ 6-month-old infants tested in the passive habituation-dishabituation experiment of Experiment 5. Comparisons are made for habituation trials and looking behavior on the faces during habituation and dishabituation. No comparisons for looking behavior on the internal facial features are made as the size of the faces presented differed among the two experiments.

In both experiments the percentage of infants that did not habituate was about the same (passive, 15%; GCLT, 14%). A paired *t*-test did not show a difference in number of habituation trials between the passive ($M = 10.35$, $SD = 2.76$) and the one disc GCLT ($M = 10.28$, $SD = 3.53$) habituation-dishabituation experiment, $t(33) = .07$, *ns*.

Figure 23, depicts the mean dwell time on the first three and the last three faces presented during the habituation phase and the new and the familiar face presented during the dishabituation phase for the infants tested in the passive and the one disc GCLT habituation-dishabituation experiment. A RM ANOVA with habituation (first three vs. last three faces) as the repeated measure variable and experiment (passive vs. one disc GCLT) as the dependent variable revealed a main effect for habituation, $F(1, 33) = 43.13$, $p < .001$, $\eta_p^2 = .57$. This main effect for habituation is in accordance with the separate paired *t*-tests performed for the passive and the one disc GCLT habituation-dishabituation experiment. This effect shows that infants' mean dwell time on the first three faces (passive, $M = 16757$, $SD = 7747$; one disc

GCLT, $M = 17866$, $SD = 15924$) was significantly higher than on the last three faces (passive, $M = 5937$, $SD = 3227$; one disc GCLT, $M = 4315$, $SD = 2861$). No interaction effect between habituation and experiment was found, $F(1, 33) = .54$, *ns*.
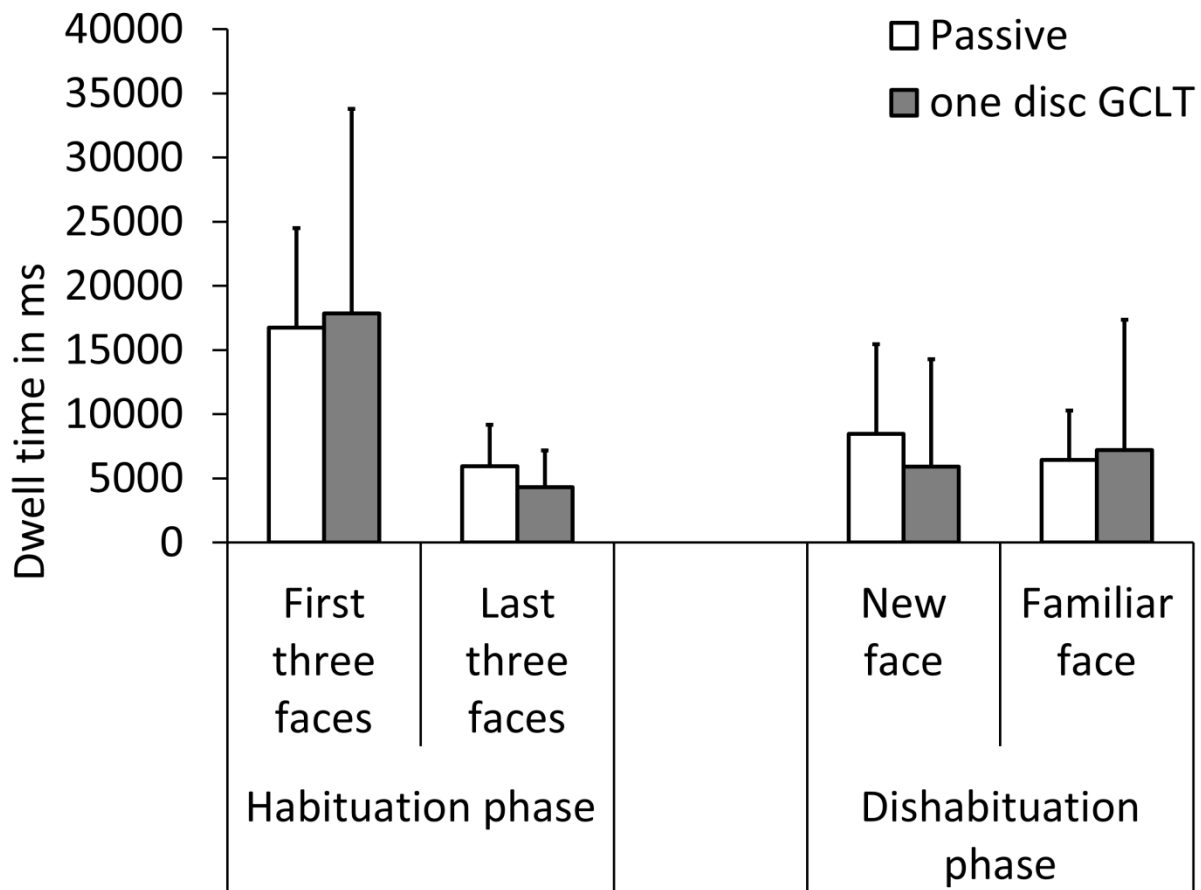
Figure 23. Mean dwell time (in ms; + SD) on the first three and last three faces presented during the habituation phase and the new and the familiar face presented during the dishabituation phase for the infants tested in the passive and the one disc GCLT habituation-dishabituation experiment.

A RM ANOVA with dishabituation (new vs. familiar face) as the repeated measure variable and experiment (passive vs. one disc GCLT) as the dependent variable did not reveal a main effect for dishabituation, $F(1, 33) = .70$, *ns*. Furthermore, no interaction effect between dishabituation and experiment was found, $F(1, 33) = 1.40$, *ns*.

Although no interaction effect between dishabituation and experiment existed, the data suggests that infants in the passive habituation-dishabituation experiment discriminated better between the new (passive, $M = 8470$, $SD = 6967$; one disc GCLT, $M = 5916$, $SD = 8354$) and

familiar (passive, $M = 6434$, $SD = 3850$; one disc GCLT, $M = 7208$, $SD = 10153$) face than the infants in the one disc GCLT habituation-dishabituation experiment.

Conclusion

In the present experiment, it was investigated whether 6-month-old infants habituate and dishabituate within a one disc GCLT habituation-dishabituation experiment. However, before this experiment started a training phase, which was identical to the one disc GCLT experiment of Experiment 1, was administered. Replicating Experiment 1, the results of the trainings phase suggest that 6-month-old infants are able to learn the association between looking at a red disc and the appearance of an animal photograph. The results showed that infants' frequently looked at the disc which triggered new animal photographs. Moreover, infants' average fixation duration on the animal photographs that were only presented for 1.5 s was higher than on the constantly presented red disc. As in Experiment 1, this finding indicates that infants did not merely look at the disc as it was highly salient per se (as spontaneous looking behavior) which might indicate R-O instead of S-R association learning. Last but not least, the results of the training phase showed that infants frequently expected new upcoming animal photographs. This result provides additional evidence of R-O association learning and suggests that it could be that infants consciously learned the gaze-contingent association. However, it has to be kept in mind that this behaviorally assessed learning could also be unconscious.

Directly after the training phase the one disc GCLT habituation-dishabituation experiment started. The results showed that there were no relations between the training phase and the one disc GCLT experiment. For the habituation phase, it was found that infants were able to habituate to the repeatedly presented stimulus as looking time to the face decreased from the first three to the last three faces presented during the habituation phase. This finding is in line with previous studies of Weir et al. (2000, 2005) who also showed that infants habituate within an operant conditioning task.

Unexpectedly, the results of this experiment also demonstrated that infants were not able to dishabituate within the one disc GCLT habituation-dishabituation experiment. Here, it was even found that infants looked longer to the familiar than to the new face. This finding is in contrast to the habituation-dishabituation literature and might be a consequence of the one disc GCLT set-up used.

When comparing the performances of the 6-month-old infants in the passive habituation-dishabituation experiment to the performances of the 6-month-old infants in the

present experiment remarkable similarities during the habituation phase were found. The percentage of infants that did not habituate as well as the number of habituation trials used were almost identical. Furthermore, infants in both experiments habituated and the decrease in looking time from the first three to the last three faces did not differ between experiments.

Considering the dishabituation phase, no significant difference in looking time from the new to familiar face between both procedures was found. Descriptively, however, it was found that infants in the passive habituation-dishabituation experiment were able to better discriminate between the new and the familiar face than infants in the one disc GCLT habituation-dishabituation experiment. In Figure 23 it can be seen that infants in the passive habituation-dishabituation experiment looked longer to the new than to the familiar face whereas infants in the one disc GCLT habituation-dishabituation experiment looked longer to the familiar than to the new face. This finding indicates that dishabituation is more difficult in the one disc GCLT habituation-dishabituation experiment than in the passive habituation-dishabituation experiment. According to the comparator model (e.g., Kavšek, 2004, 2013) dishabituation occurs when a new stimulus is compared to the mental representation of an old stimulus that is built up during habituation and an infant is able to discriminate between both of them. To speculate, the difference in dishabituation found in Experiment 5 and 6 might be due to different encoding of the face during habituation. In the one disc GCLT habituation-dishabituation experiment the face stimuli were smaller and there was an additional red disc to look at which could have made the encoding of the repeatedly presented face more difficult. Furthermore, it might have been that the gaze-contingent procedure of the one disc GCLT habituation-dishabituation experiment interfered with dishabituation. Such active control could have distracted infants from encoding the facial stimulus. Moreover, it might have been that infants habituated to the triggering of a new stimulus (to the gaze-contingent association) instead of to the stimulus shown. However, this speculation contradicts the findings of Weir et al. (2000) who state that in their study infants habituated to the reward instead of to the association itself. More research in this area is needed to further disentangle where infants habituated to.

Discussion

In this chapter it was examined whether the one disc GCLT can be used to investigate habituation-dishabituation learning in an active infant controlled manner. Moreover, it was examined whether such active control over the visual environment provided by the GCLT influences infants' habituation-dishabituation learning. Therefore, a passive (Experiment 5) as

well as a one disc GCLT (Experiment 6) habituation-dishabituation experiment were conducted. A comparison of infants' habituation-dishabituation learning in both experiments was made.

The comparison of both experiments suggests that the one disc GCLT can be used to investigate infants' habituation-dishabituation learning in an active infant controlled manner. In addition to Experiment 1, the one disc GCLT habituation-dishabituation experiment demonstrated that infants learned to look at the disc which triggers the appearance of a new stimulus in a one disc GCLT set-up when stimuli are presented for a longer period of time. Moreover, it was found that infants were able to habituate within a one disc GCLT set-up. This finding may indicate that infants learned to look at the disc when interest in the repeatedly presented stimulus faded away. Nevertheless, it can also be argued that infants habituated to the triggering of a new stimulus (to the gaze-contingent association) instead of to the stimulus shown.

In addition, this chapter highlights that active control over the visual environment provided by the GCLT might influence infants' habituation-dishabituation learning as differences in looking time on the faces during dishabituation between both experiments were found. This result suggests that giving active control over the visual stimuli presented within a habituation-dishabituation task might influence infants' discriminatory recognition memory.

Acknowledgements

Chapter 8

General Discussion and Future Research

General Discussion

In this dissertation a lifespan examination on how infants and younger as well as older adults learn to control their visual environment with looking behavior within the newly developed gaze-contingent learning task (GCLT) was made. Within the GCLT subjects had to look at a disc in order to trigger a new stimulus that appeared at a specific location on the display screen. To be in control over the visual environment with looking behavior within the GCLT subjects had to learn that there is a gaze-contingent association between their looking behavior at the disc and the visual effect.

Three lines of GCLT experiments with infants, younger, and older adults were conducted to examine how gaze-contingent associations are learned over the lifespan. In these experiments, one and two disc(s) GCLT were used. In the one disc GCLT a disc was presented at the right side of the display screen and every time a subject looked at this disc a stimulus appeared at the left side of the display screen. The two discs GCLT differed from the one disc GCLT in that not one but two discs were presented. These discs were presented at the left and right side of the display screen and only one of the two discs (within one session only left or right) had the function of triggering a new stimulus (functioning disc) that appeared in the middle of the display screen. The other disc was non-functioning. Within the one and two disc(s) GCLT experiments, infants' as well as adults' gaze-contingent association learning was assessed behaviorally by measuring looking behavior. Such looking behavior might indicate R-O association learning, however, it is unknown whether this learning reflects conscious or unconscious learning of the gaze-contingent association. In addition, adults' gaze-contingent association learning was measured verbally by administering a questionnaire. In contrast to looking behavior, such a verbal indicator of gaze-contingent association learning directly shows whether the association was learned consciously or not.

In the first line of experiments the GCLT was for the first time tested with infants and young adults. In Experiment 1 it was investigated whether infants learned the gaze-contingent association within the one disc GCLT. Moreover, in Experiment 2 it was examined whether infants as well as young adults learned the gaze-contingent association within the two discs GCLT. Within the second line of experiments the learning of the gaze-contingent association within the two discs GCLT was further investigated with adult subjects. Here, perceptual factors that might influence gaze-contingent association learning were examined. In

Experiment 3 it was investigated whether contiguity (situational information) influenced young adults' gaze-contingent association within the two discs. Furthermore, the influence of prior knowledge related cues on learning the gaze-contingent association within the two discs GCLT by younger and older adults was tested in Experiment 4. In the third line of experiments the one disc GCLT was further tested with infants. In this research line, the main focus was not on learning the gaze-contingent association per se, however, it was examined whether the one disc GCLT could be used to give infants' active control within a passive looking behavior task in which they have normally no control. Therefore, a passive habituation-dishabituation experiment (Experiment 5) was compared to a one disc habituation-dishabituation experiment (Experiment 6).

All in all, these experiments provide a lifespan perspective on how infants and younger as well as older adults learn to control their visual environment within GCLT set-ups. Now, the gaze-contingent association learning results for each age group will be separately discussed. First, an overview on how infants' learned the gaze-contingent association within the one and the two disc(s) GCLT is provided. Afterwards, younger and older adults' gaze-contingent association learning within GCLT set-ups is discussed.

The results of the infant experiments suggest that infants are able to learn to control their visual environment within GCLT set-ups. In these experiments looking behavior analyses indicate that infants can learn response-outcome (R-O) associations between looking at a disc and a visual effect within the one and the two disc(s) GCLT. In the one disc GCLT with the shortly presented animal photographs as stimuli (Experiment 1 and trainings phase of Experiment 6), it was found that infants frequently looked at the disc and that their average fixation duration on the stimuli was higher than on the disc. Moreover, the results also demonstrated that infants expected the animal photograph to appear within a few trials. These findings suggest that infants did not merely look at the disc as it was highly salient per se but that they expected something to happen after they looked at it. In addition to these findings, the one disc habituation-dishabituation experiment (Experiment 6) showed that infants also learned to look at the disc when stimuli were presented for a longer period of time. Infants' habituated to the repeatedly presented stimulus which may indicate that they learned to look at the disc when their interest in the repeatedly presented stimulus faded away. Moreover, in the two discs GCLT (Experiment 2), it was found that infants frequently looked at the functioning disc and that they made more functioning than non-functioning disc patterns. These findings demonstrate that infants learned to discriminate between the functioning and non-functioning discs. Altogether these looking behavior results indicate that infants did not

learn a simple mechanistic stimulus-response (S-R) association but that they learned an R-O association between looking at the disc and the appearance of an animal photograph within the one and the two disc(s) GCLT.

Although the looking behavior measured in the one and two disc(s) GCLT experiments suggest that infants learned R-O associations within GCLT set-ups, it remains unclear whether this association is learned consciously or not. On the one hand, it could be that this behaviorally assessed gaze-contingent association learning reflects a mechanistic unconscious learning process in which infants do not learn that their own behavior produced the effect. On the other hand, it can be speculated that some infants could have learned the gaze-contingent association consciously.

The topic of whether infants become consciously aware that they produced an effect with their own behavior is thoroughly debated by various infant researchers (e.g., Kenward, 2010; Rochat and Striano, 2000). In a review, Rochat and Striano (2000) suggest that infants manifest a sense of themselves as an agent in the environment from very early on. However, in this literature it is also argued that such an early sense of agency might be unconscious. The findings of Experiment 2 contribute to this discussion in that they suggest that some infants might have learned the gaze-contingent association consciously. Here, it was found that infants' looking behavior closely matched the looking behavior of adults who became consciously aware of the R-O association but did not match the looking behavior of adults who did not become consciously aware of the R-O association. This result indicates that some of the infants might have learned the gaze-contingent association consciously. However, with looking behavior as the only measure of infants' gaze-contingent association learning no one ever knows for sure whether this learning is consciously or not.

For infants it was not only investigated whether they are able to learn a gaze-contingent association within GCLT set-ups, however, Chapter 7 (Experiment 5 and 6) was conducted to examine whether the one disc GCLT could be used to give infants active control within a passive looking behavior task in which they normally have no control. The comparison of the passive and active gaze-contingent habituation-dishabituation experiments suggests that the one disc GCLT can be used to investigate infants' habituation-dishabituation learning in an active infant controlled manner. However, the results also indicate that active control over the visual environment provided by the GCLT might influence infants' habituation-dishabituation learning. Differences in looking time on the faces during dishabituation between both experiments were found. Therefore, this result suggests that

giving infants active control over the visual stimuli presented within a habituation-dishabituation task could influence their discriminatory recognition memory.

In sum, the results of the infant experiments suggest that infants are able to learn to control their visual environment within GCLT set-ups. Looking behavior measures indicate that infants learn gaze-contingent associations within the one and the two disc(s) GCLT. However, it is still an open question as to whether infants learn such an association consciously or not. Moreover, Chapter 7 showed that such active control, which the GCLT provides, can be implemented in a passive looking behavior task. Nevertheless, that chapter also demonstrated that such active control might influence infants' learning within that task.

The results of the adult experiments demonstrated that learning to control the visual environment with looking behavior within GCLT set-ups is hard to learn for adult participants. In these experiments, looking behavior analyses and verbally assessed gaze-contingent association learning showed that the learning of the gaze-contingent association within the two discs GCLT is not so easy for young adult participants. In all versions of the two discs GCLT in which young adults were tested (Experiments 2-4), it was found that a large group (about 50%) of young adult participants could not verbally explain the gaze-contingent association (non-solvers). Moreover, it was demonstrated that these non-solvers showed different looking behavior than young adult participants who could verbally explain the gaze-contingent association (solvers). Solvers had shorter click intervals and made more functioning disc patterns than non-solvers. Moreover, solvers made more functioning than non-functioning disc patterns whereas this preference was not found for non-solvers. These results suggest that non-solvers neither learned the gaze-contingent association consciously nor unconsciously.

For young adult participants it was also investigated whether contiguity and prior knowledge related cues influenced gaze-contingent association learning within the two discs GCLT. The results of Experiment 3 showed that contiguity did not influence young adults verbally assessed gaze-contingent association learning. However, the results also demonstrated that contiguity influenced young adults looking behavior on the discs. It was found that young adults in the short latency condition had shorter click intervals and made more functioning disc pattern than young adults in the long latency condition. Moreover, young adults in the short latency condition made more functioning than non-functioning disc pattern whereas this effect was not found for the young adults in the long latency condition. This result might indicate that contiguity influenced young adults' unconscious learning of the

gaze-contingent association whereas it did not influence young adults' conscious learning of the gaze-contingent association.

The results of Experiment 4 showed that prior knowledge related cues did not influence young adults' verbally assessed gaze-contingent association learning. Moreover, it was found that young adults looking behavior was also not influenced by the prior knowledge related cues that were used. Therefore, these findings suggest that the prior knowledge related cues did not influence young adults' conscious nor unconscious learning of the gaze-contingent association.

The results of the experiment with older adults (Experiment 4) demonstrated that learning to control the visual environment with looking behavior within GCLT set-ups is especially hard to learn for older adult participants. In these experiments looking behavior analyses and verbally assessed gaze-contingent association learning showed that the learning of the gaze-contingent association within the two discs GCLT is not so easy for older adults. In all three knowledge related versions of the two discs GCLT it was found that a large group (about 70%) of older adult participants could not verbally explain the gaze-contingent association. Similar as to what was found for the young adults it was demonstrated that these non-solvers showed different looking behavior than solvers.

For older adults it was also examined whether prior knowledge related cues influenced gaze-contingent association learning. Here, it was found that prior knowledge related cues influenced older adults' verbally assessed gaze-contingent association learning. A higher percentage of older adult solvers were found in the grey switches than in the red discs version of the two discs GCLT. However, no effect of prior knowledge related cues on older adults looking behavior was evident (see Chapter 6, Figure 17, page 80). Therefore, these results suggest that prior knowledge related cues made it easier for older adults to consciously learn the gaze-contingent association within the two discs GCLT.

In brief, the adult experiments suggest that learning to control the visual environment with looking behavior within the two discs GCLT is hard for young and especially hard for older adults. This is indicated by verbally as well as behaviorally assessed gaze-contingent association learning. Moreover, it was found that contiguity may influence young adults' unconscious learning of the gaze-contingent association whereas prior knowledge related cues might influence older adults' conscious learning of the gaze-contingent association.

Taken together all of the findings from the infant and adult experiments conducted in this dissertation, it can be concluded that the GCLT can be used to give subjects of different

ages control over their visual environment with looking behavior. The experiments provided evidence that infants and younger as well as older adults are able to learn gaze-contingent associations within GCLT set-ups. However, developmental differences in learning such gaze-contingent associations were found. On the one hand, looking behavior analyses showed that infants learn such gaze-contingent associations very quickly. On the other hand, analyses of verbally assessed gaze-contingent association learning and looking behavior revealed that this learning is difficult for adult subjects. Here, it was even found that this learning might be especially difficult for older adults.

The age differences found during gaze-contingent association learning within GCLT set-ups can be explained by developmental differences in the underlying learning processes that contribute to and in the perceptual processes that are involved during this learning. In Chapter 4 (see pages 41-46) it was discussed that the learning and the perceptual processes, which are mainly involved during operant conditioning learning may vary over different stages of lifespan development. Considering the learning processes, it was discussed that a mechanistic process might be important during operant conditioning learning in infancy (e.g., Kenward, 2010) whereas higher cognitive processes may be more important during operant conditioning learning in adulthood. However, this might not be the case for all higher cognitive processes in older adulthood. It was argued that higher cognitive processes which are part of mechanics could be less important during operant conditioning learning in older adulthood whereas higher cognitive processes which are part of pragmatics may be more important (e.g., Baltes, 1987; Birney & Sternberg, 2006; Cattell, 1971; Horn & Cattell, 1967). Considering the perceptional processes, it was discussed that bottom-up processes and situational information might be important during infants' operant conditioning learning whereas top-down processes and prior knowledge could become more important during operant conditioning learning as age increases (e.g., Açık et al., 2010). Briefly worded, these theoretical considerations suggest that a mechanistic learning process and that situational information are important during infants' operant conditioning learning whereas higher cognitive processes, and especially prior knowledge, become more important as age increases.

Regarding the findings of this dissertation it can be speculated that a mechanistic learning process and a lack of prior knowledge made the learning of a gaze-contingent association within GCLT set-ups easy for infants. In this case, infants just looked at the situational information on a display screen and learned to look at the disc that triggered a new stimulus.

For adults it can be argued that the use of higher cognitive processes and especially an increase in prior knowledge might have interfered with their learning of the gaze-contingent association. Here, it could have been that incongruent prior knowledge about the task (having learned over many years that looking at a display screen does not produce any effect on the environment; e.g., Alloy & Tabachnik, 1984; López & Shanks, 2008; Young, 1995) hindered this learning.

Evidence that prior knowledge might have negatively interfered with gaze-contingent association learning comes from the finding that this learning was harder for older than for younger adults. This age difference in gaze-contingent association learning can also be explained by an age related decrease in mechanics, however, the findings of Experiment 4 suggest that this result might be due to an age related increase in prior knowledge. Here, it was found that prior knowledge related cues improved older adults' conscious learning of the gaze-contingent association. Therefore, it can be argued that an increase in prior knowledge made it easier for older adults to learn the gaze-contingent association when prior knowledge related cues were presented. However, without these cues it might have been difficult for older adults to learn the gaze-contingent association as prior knowledge might have interfered with the learning.

To conclude, this dissertation showed that the GCLT can be used to give infants, younger, and older adults control over their visual environment with looking behavior. Infants, younger, and older adults are able to learn gaze-contingent associations within GCLT set-ups. However, age differences in this learning have been found. These age differences can be explained by developmental differences in the underlying learning processes that contribute to and in the perceptual processes that are involved during this learning. A mechanistic learning process and a lack of prior knowledge might have made the learning of a gaze-contingent association easy for infants. In contrast, an increase in higher cognitive processes and most important an increase in prior knowledge, which could be incongruent with the association that had to be learned, might have made gaze-contingent association learning more difficult for younger and especially hard for older adults.

Future Research

The results of the experiments and the general discussion of this dissertation show that there is a need for more research with active gaze-contingent looking behavior tasks. More research on how and when active visual environment control within active gaze-contingent

looking behavior tasks is learned is necessary. Future research with such tasks should be conducted within infant, younger and older adult populations as well as over the lifespan.

Within infancy research such gaze-contingent looking behavior tasks have a lot of potential as they provide the opportunity to give preverbal infants who have limited motor repertoires the possibility to actively control their visual environment. As this dissertation presents the first experiments in which the GCLT is tested with infants, more research on gaze-contingent association learning in infancy is necessary.

In the first place, infants' gaze-contingent association learning within GCLT experiments should be further investigated. The infant experiments conducted in this dissertation made use of simple one and two red disc(s) GCLT's in which animal photographs were used as stimuli. Future research might examine infants' gaze-contingent association learning within GCLT's with more or different looking non-functioning discs as well as with other stimuli than disappearing or slow fading animal photographs. During the experiments conducted in this dissertation the spatial location of the functioning disc was not changed within a session. Future research might investigate whether infants learn gaze-contingent associations when the stimulus that is used as the functioning disc changes spatial location. One recently published study of Tummeltshammer, Mareschal, and Kirkham (2014) already investigated whether infants could learn gaze-contingent associations for a specific stimulus (comparable to the functioning disc) that changes spatial location. In this study a similar gaze-contingent task as the two discs GCLT was used. This study consisted of gaze-contingent trials in which looking at the gaze-contingent stimulus that was randomly presented either at the left or right side of the display screen triggered the appearance of a cartoon. It was examined whether 6- and 8-month-old infants learned a gaze-contingent association when equal salient non-contingent and gaze-contingent stimuli were used as well as when the non-contingent stimulus was more salient than the gaze-contingent stimulus. This study showed that 6- and 8-month-old infants are able to learn a gaze-contingent association when equally salient stimuli are used as non-contingent and gaze-contingent stimuli. However, when a more salient non-contingent than gaze-contingent stimuli was used, only 8- but not 6-month-old infants learned the gaze-contingent association. Extending the results of the GCLT experiments with infants in this dissertation, this study showed that infants are able to learn gaze-contingent associations between a stimulus that changes spatial location and a visual effect. However, far more variations of the task are possible, and therefore more research is necessary.

Second, it should be further investigated whether infants learn gaze-contingent associations within GCLT's consciously or unconsciously. Within a new research project called "Learning Gaze-Contingent Associations in Infancy" conducted in Frankfurt Main, Germany, this theme is further examined This research project is a cooperation between the Frankfurt Institute of Advanced Studies (FIAS) and the Department of Psychology of the Goethe-University Frankfurt and is supported by the Deutsche Forschungsgemeinschaft (DFG). Within this research project the GCLT is further tested with young infants. Infants of 6-, 8-, and 10-months of age are either tested in an active (gaze-contingent condition) or a passive (yoked control condition) two discs GCLT experiment. In the gaze-contingent condition the same two discs GCLT as in Experiment 2 is used. Infants in the yoked control condition see a playback of a video from an infant in the gaze-contingent condition. In this project it is examined whether infants' looking behavior on the discs in the gaze-contingent condition differs from infants' looking behavior on the discs in the yoked control condition. Infants' looking behavior on the discs in the yoked control condition serves as a control for spontaneous looking behavior on the discs when they are non-contingent (S-R association learning). Therefore, a comparison of infants' looking behavior on the discs in the gaze-contingent and the yoked control condition will provide information on R-O association learning. This R-O association learning could indicate that infants used higher cognitive processes and that they might have consciously learned that the effect was produced by their own behavior.

Third, it should be further investigated whether such active control, which active gaze-contingent looking behavior tasks provide, influences infants' learning within passive looking behavior tasks. In this dissertation it was already examined whether such active control influences infants' habituation-dishabituation learning. Here, similarities as well as differences between a passive and active GCLT habituation-dishabituation experiment were found. These findings indicate that active gaze-contingent control could influence learning in passive looking behavior tasks. Therefore, more infant research with active gaze-contingent looking behavior tasks is necessary to further disentangle whether such active control influences infants' learning within habituation-dishabituation but also within other passive looking behavior tasks like, for example, in a VExP.

Last but not least, future research with active gaze-contingent looking behavior tasks in infant populations should focus on age and individual differences as well as on convergent, discriminant, and predictive validity of these paradigms. Experiment 1 as well as the study of Tummeltshammer et al. (2014) revealed age differences in learning a gaze-contingent

association within GCLT set-ups. Therefore, more research is necessary to investigate whether still younger infants can learn gaze-contingent associations and what influences this learning over the first year of life.

Individual differences should also be investigated. The importance of an individual difference approach has been shown by the passive habituation-dishabituation experiment (Experiment 5). In this experiment it was found that habituation speed was related to individual differences in looking behavior on faces during habituation as well as dishabituation. This result suggests that a slower habituation speed with specific looking behavior on the eyes might give an advantage for face discrimination in some specific situations. For GCLT experiments it might also be interesting to take a look at individual differences in infants' gaze-contingent association learning. Such individual differences were not discussed in Chapter 5 and 7 of this dissertation, however, naturally such individual differences exist. For example, Appendix Figure A shows the reaction times to the upcoming stimuli plotted as a function of triggered stimuli for four different infants in Experiment 1. Here, it can be seen that there are large differences in infants' reaction times. Moreover, the large standard deviations found for the infants' other looking behavior data in Experiment 1, 2, and 6 also suggest that there are individual differences in infants' gaze-contingent association learning. In future research it might be worthwhile examining how such individual differences in infants' gaze-contingent association learning relate to other cognitive abilities. This research topic is also part of the research project "Learning Gaze-Contingent Associations in Infancy" conducted in Frankfurt Main, Germany. Here, it is examined whether infants' performances on the two discs GCLT relate to performances on the cognitive scale of the Bayley Scales of Infant Development (Bayley, 2006), performances in a passive habituation-dishabituation experiment with faces (the same as in Experiment 5) and ratings on a temperament questionnaire (Pauli-Pott, Mertesacker, & Beckmann, 2003). This project aims to provide a more detailed description of gaze-contingent association learning and to gain an insight into which cognitive abilities are involved in learning such tasks. Moreover, when relations between individual differences in gaze-contingent association learning and other cognitive processes are found this shows that active gaze-contingent looking behavior tasks could be used as an early indicator for disabilities (e.g., autisms) or perhaps as a predictive tool (e.g., intelligence).

Within younger and older adult populations such active gaze-contingent looking behavior tasks should also be further investigated. Such tasks do not only provide great opportunities to develop input systems for people with various types of locked-in syndrome

(for an overview of this syndrome see Ramos-Murguialday et al., 2011) and paralysis, however, they also offer possibilities to develop new input systems that can be implemented in daily life products like, for example, mobile phones and tablets that are for general usage.

Future research with active gaze-contingent looking behavior tasks in adulthood should focus on intuitive set-up designs and user friendliness. Some studies already showed that adults are able to learn gaze-contingent associations when they are instructed (e.g., Jacob, 1990; Murata, 2006; Sibert & Jacob, 2000; Ware & Mikaelian, 1987), however, the experiments conducted in this dissertation demonstrated that such associations are not so easily learned within the GCLT without instructions. Future research should focus on the conditions under which uninstructed adults learn gaze-contingent associations as instructions are not always provided. Similar as to what has been done within the present dissertation, future research could focus on situational information and prior knowledge related cues that might enhance gaze-contingent association learning. Moreover, it might be interesting to further investigate age differences in younger and older adults' gaze-contingent association learning.

Finally, future research with active gaze-contingent looking behavior tasks over the lifespan should be conducted. In the present dissertation the GCLT was used to make a lifespan examination on how infants, younger, and older adults learn gaze-contingent associations. Age differences in learning gaze-contingent associations within the GCLT were found. This lifespan investigation provided the opportunity to compare infants' behaviorally assessed gaze-contingent association learning to adults' behaviorally as well as verbally assessed gaze-contingent association learning. Such a comparison provided an additional indication that infants' might have learned the gaze-contingent association within GCLT set-ups consciously. More research with active gaze-contingent looking behavior tasks over the lifespan is now necessary to further unravel how infants, younger, and older adults learn gaze-contingent associations. Such future research will not only show whether there are changes in gaze-contingent association learning over the lifespan, however, it will also enable researchers to compare infants' behaviorally measured learning with adults' verbally and behaviorally measured learning which may provide a deeper understanding on what infants might learn.

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Eidesstattliche Versicherung

Ich erkläre hiermit an Eides Statt, dass ich die vorgelegte Dissertation über

"The Gaze-Contingent Learning Task: How Infants, Younger, and Older Adults,
Learn to Control their Visual Environment with Looking Behavior in Experimental Research"

selbständig angefertigt und mich anderer Hilfsmittel als der in ihr angegebenen nicht bedient habe, insbesondere, dass alle Entlehnungen aus anderen Schriften mit Angabe der betreffenden Schrift gekennzeichnet sind.

Ich versichere, die Grundsätze der guten wissenschaftlichen Praxis beachtet, und nicht die Hilfe einer kommerziellen Promotionsvermittlung in Anspruch genommen zu haben.

Frankfurt am Main, den   …...............................   ....

(Unterschrift)

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Appendix

Questionnaire A

An Example of the Questionnaire used

Exploration

1. Geburtstag ……..-……..-……………
2. Geschlecht w / m
3. Beruf/Studiengang …………………………………………………………………….
4. Brille oder Kontaktlinsen (Stärke) …………………………………………………………

Wie fanden Sie das Experiment /Wie haben Sie sich gefühlt?

Gab es Umstände, die Sie während des Versuches gestört haben?

Wie fanden Sie die Bilder/ Haben Sie die gesamte Bilderserie gesehen? Wenn nein, warum nicht?

Wie fanden Sie die roten Punkte im Vergleich zu den Bildern?

Was denken Sie, worum es in der Studie geht?

Wissen Sie, welche Funktion die roten Punkte haben?

Hatten Ihre Augenbewegungen Einfluss auf den Versuchsablauf? Wenn ja, inwiefern?

Hatte es irgendwelche Auswirkungen, wenn Sie auf einen der beiden roten Punkte geschaut haben? Wenn ja, welcher Punkt war es und was ist passiert?

Haben Sie bemerkt, dass wenn Sie einen roten Punkt angeschaut haben, dies ein neues Bild erschienen ließ?

Sonstige Bemerkungen:

Table A

Sizes of areas of interest (AOIs) in pixels

Size in visual angles (from a distance of 600 mm) is shown in parentheses

| Stimulus	Pose	AOI	Area		Coordinates (top, left)
			Width	Height	x, y
Habituation/ Familiar face	Frontal	Picture	528 (16.48)	692 (22.92)	37, 248
		Eye left	105 (3.29)	60 (2.01)	295, 380
		Eye right	105 (3.29)	60 (2.01)	295, 535
		Nose	120 (3.77)	85 (2.85)	355, 450
		Mouth	200 (6.28)	85 (2.84)	450, 410
	Left	Picture	528 (16.48)	692 (22.92)	37, 248
		Eye left	90 (2.81)	60 (2.01)	295, 335
		Eye right	120 (3.77)	60 (2.01)	290, 475
		Nose	120 (3.76)	85 (2.85)	355, 385
		Mouth	200 (6.28)	85 (2.84)	450, 365
	Right	Picture	528 (16.48)	692 (22.92)	37, 248
		Eye left	120 (3.77)	60 (2.01)	290, 425
		Eye right	90 (2.81)	60 (2.01)	295, 595
		Nose	120 (3.76)	85 (2.85)	355, 520
		Mouth	200 (6.28)	85 (2.84)	450, 465
New face	Frontal	Picture	528 (16.48)	692 (22.92)	37, 248
		Eye left	105 (3.29)	60 (2.01)	315, 390
		Eye right	105 (3.29)	60 (2.01)	315, 545
		Nose	120 (3.77)	85 (2.85)	375, 460
		Mouth	200 (6.28)	85 (2.84)	470, 420

Figure A
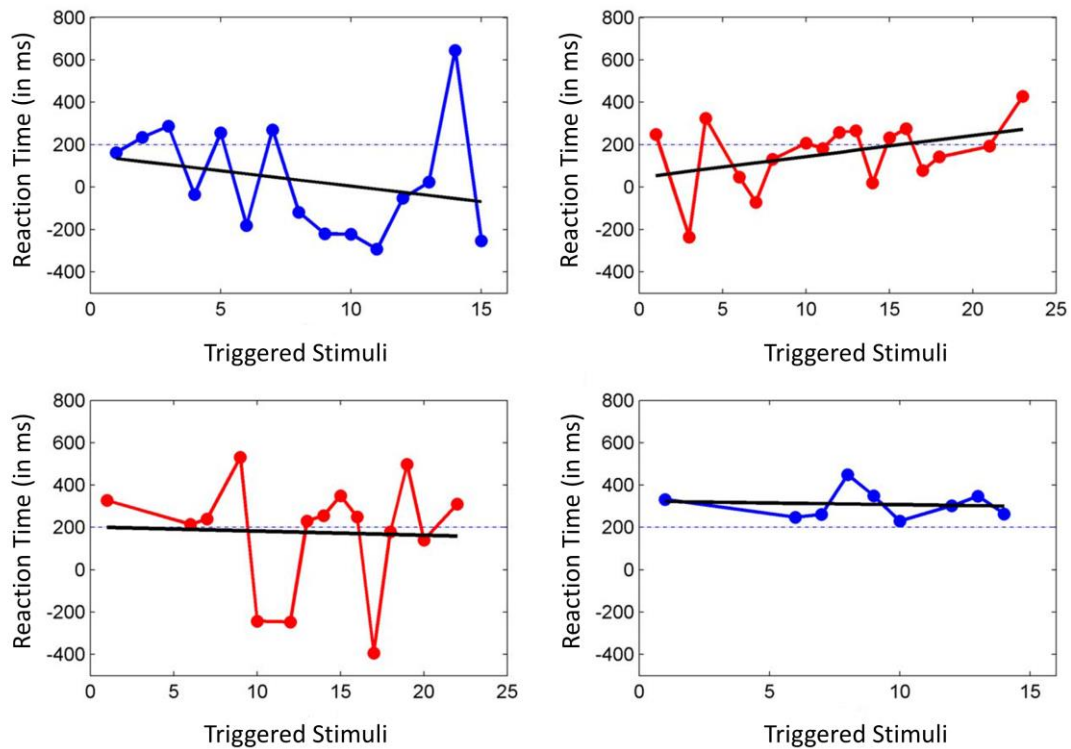
Figure A. Infants' reaction time as a function of triggered stimuli. Each subplot represents one individual. 6-month-old infants are plotted in blue whereas 8-month-old infants are plotted in red. The dashed line is the 200 ms criterion for anticipations. Large individual differences in infants' reaction times were observed. Adapted from "Infants in Control: Rapid Anticipation of Action Outcomes in a Gaze-Contingent Paradigm", by Wang et al. (2012), *PLoS ONE*, *7,* e30884. doi:10.1371/journal.pone.0030884.g005.