INTRODUCTION

In their everyday lives, people engage in many different social exchange processes, strive for interactions, or exchange thoughts and feelings with others (e.g., Nowak, Vallacher, & Zochowski, 2005; Vallacher, Nowak, & Zochowski, 2005). They all share the experience that coordinating their own actions with others' plays a key role during these interaction processes. In other words, in many social situations we would not succeed if we were not able to coordinate our actions with those of others.

To begin with, I want to clarify the key characteristics of *interpersonal action coordination* that are relevant for the present study. A beautiful example by Bernieri and Rosenthal (1991) describes interpersonal action coordination among members of a jazz band while improvising:

> A jazz band is composed of separate entities generating different sounds that fit together to create the perception of a single piece of music. Thus another element in jazz is the ability to mesh and interweave smoothly the various components of the total piece of music. ... This means synchronizing with the others. The musicians must be playing at the same tempo. They must increase and decrease the loudness together. The music played by each instrument sometimes complements and intertwines with the others. A band thus becomes a unit playing one song: it "grooves." When people interact, their behaviors intertwine as do the sounds from different instruments in a band (pp. 403).

This example summarizes several aspects of coordination processes that are related to the focus of the present study. First, as is also true for the jazz musicians in the example, interpersonal action coordination is very often accomplished with great temporal precision. Interpersonally coordinated processes that are organized in time, or sometimes even occur simultaneously, can be subsumed under the notion of *synchronization*. *Interpersonal action synchronization* is proposed to be an important facet of social life (e.g., Sebanz, Bekkering, & Knoblich, 2006).

Second, members of a jazz band synchronize their actions to "create the perception of a single piece of music." This *shared goal* is implicitly defined in the situation. The musicians have their own *style* and *tempo* and their individual *ability to synchronize their physical movements*. Still, the interaction outcome is more than just the sum of all individual contributions (e.g., Bratman, 1992; Searle, 1990). A complete sound cannot be attained if each musician solely plays his or her individual voice. Moreover, the interpersonal synchronization process that takes place among the musicians is responsible for the achievement of euphonious music.

Third, synchronizing with the band members requires the ability to perceive the others' actions (e.g., loudness, tempo) and react accordingly. Furthermore, individuals' experience in playing with other musicians may be taken into account when anticipating own and others' actions. That is, in general, synchronizing one's actions with others' requires perceptive (i.e., sensorimotor) skills as well as experience-based knowledge (i.e., social competencies).

Goal-directed interpersonal synchronization processes, in which each individual has to adjust his or her action parameters to reach an interpersonally defined goal, are not at all limited to making music with others. For instance, when we talk to each other, move a table together, or simply walk next to another person, each individual's behavior is closely linked to that of the interaction partner in time to facilitate the achievement of a shared goal in a fluent way. The ability to synchronize with others to reach shared goals therefore shapes our capability to interact in general and is proposed to have an adaptive function in different interaction processes.

Astonishingly, so far, there has not been much empirical research on goal-directed interpersonal action synchronization and its underlying mechanisms. Although the existence of the phenomenon itself is beyond debate, it is still an open question whether and why some people find it easier to synchronize during interactions than others. That is, it has not been investigated so far whether there are stable individual differences among people that predict which pairs or groups are more likely to synchronize (e.g., Bernieri & Rosenthal, 1991). Moreover, there is neither theory nor empirical evidence on the development of interpersonal action synchronization across the lifespan. It has been reported that interpersonal synchronization of behavior occurs very early in infancy (e.g., Condon & Sander, 1974a, 1974b). Furthermore, it has been argued that the ability to synchronize with others is a basic function for a wide range of different social processes and developmental outcomes throughout the lifespan (e.g., Chartrand & Bargh, 1999; Harrist & Waugh, 2002; Warner, 1992). However, the lifespan development of the ability to synchronize with others has not been investigated so far. Therefore, three main questions were derived for the present investigation: How does the ability to synchronize with others develop across the lifespan (i.e., from childhood to older adulthood)? What are the underlying mechanisms? And what are possible outcomes of accurate interpersonal action synchronization?

In line with lifespan developmental theories (e.g., P. B. Baltes, 1987, 1990), I propose that the development of interpersonal action synchronization is based on two basic components and their interaction, namely *life mechanics* (e.g., sensorimotor abilities) and *life pragmatics* (e.g., social competencies). As described above, interpersonal action synchronization processes require sensorimotor skills and social competencies. Therefore, I expect that individual and age-related differences in these antecedents affect the development of the ability to synchronize with others to reach a shared goal. Furthermore, I suggest a positive relationship between more accurate interpersonal action synchronization and a more positive subjective experience of the interaction and the respective interaction partner.

This dissertation is organized as follows: First, I will give an overview of central empirical evidence related to interpersonal action synchronization and derive a theoretical framework that allows embedding of this research into the theory of lifespan psychology. Subsequently, the rationale behind the paradigm to investigate interpersonal action synchronization will be introduced. In addition, I will derive a working model from the theoretical framework to introduce the research questions and hypotheses. The second part provides a description of the research paradigm and instruments as well as a summary of the analytical approach. After presenting the results, I will finally conclude with a discussion of the findings with respect to the lifespan development of interpersonal action synchronization, its antecedents, and individual consequences.

1. THEORETICAL BACKGROUND

As humans are a very social species, they frequently experience situations in which they need to coordinate their actions with those of other people around them. Examples include coordination during different work processes, playing music, doing collective sports, or dancing together. More specifically, it is often necessary to adjust the *timing* of one's own actions with regard to others' actions to reach a shared goal in a fluent way. I refer to these coordination processes that take place in the interpersonal domain on a highly precise temporal dimension as *interpersonal action synchronization*. The aim of the present study was to investigate how individuals' ability to synchronize their actions with those of others changes across the lifespan (i.e., from childhood to older adulthood).

The following sections will theoretically embed the investigation of the development of interpersonal action synchronization into a lifespan developmental context. First, I will give a definition and a short description of the phenomenon itself. After this, earlier research focusing on different synchronization processes will be reviewed. In the second section, I will take a developmental perspective on interpersonal action synchronization and summarize relevant empirical results. This will finally lead to the introduction of a theoretical framework that relates the development of interpersonal action synchronization to two interrelated functional components, namely, *life mechanics* and *life pragmatics*.

1.1 Interpersonal Action Synchronization

Synchronization (greek: *σύν = together; χρόνος = time*) is defined as the concurrence of events in time. Synchronization processes have been described in a wide range of systems: For example, as early as in the 17th century, Christiaan Huygens already investigated the mechanical synchronization between two pendulums as a physical phenomenon (e.g., Heckscher, 1913). Since then, synchronization has been described in various contexts, for example, in computer science, physics, multimedia, and music. In these contexts, synchronization is consistently defined in terms of the temporal distance between two or more events (e.g., Pikovsky, Rosenblum, & Kurths, 2001).

Various natural systems show a tendency to synchronize. In animals and humans, a ventral region in the hypothalamus has been found to control the timing and synchronization of circadian cycles, such as hormone cycles and sleep rhythms (e.g., Birbaumer & Schmidt, 1996; Pouthas, Provasi, & Droit, 1996). Furthermore, individuals' time keepers allow the adjustment (i.e., synchronization) to external rhythms (e.g., day–night cycles). For example, mammals' biological cycles non-intentionally adjust to day–night cycles when changing time zones (i.e., individual synchronization; Aschoff, 1984; Yamazaki, Abe, Numano, Hida, Block, Sakaki et al., 2000).

When two or more time keepers co-occur, cycles often tend to synchronize between systems as well. For example, schools of fish or swarms of bees or birds coordinate their behavior very precisely in time (e.g., Hubbard, Babak, Sigurdsson, & Magnusson, 2004; Inada & Kawachi, 2002). This phenomenon also occurs in groups of humans (i.e., interpersonal synchronization). For example, audiences often synchronize their clapping over time (e.g., Neda, Ravasz, Brechet, Vicsek, & Barabasi, 2000). Further studies on humans report menstrual synchrony between women who live together, and couples who share a bed were found to synchronize their movements during their sleep (e.g., Hobson, 1995; McClintock, 1971). To conclude, synchronization can occur between one individual and external time keepers or among two or more individuals. Synchronization processes also differ with regard to the cycling time units (e.g., milliseconds, minutes, months, etc.).

The synchronization processes described so far do not require intention, that is, interpersonal behavior synchronizes without a specified goal. Beyond behavioral synchronization, humans also synchronize their actions with each other intentionally to reach a *shared goal*. Shared goals are implicitly or explicitly endorsed by two or more individuals within a specific interaction. For example, if a group of people push a broken car or do rope tugging, individuals need to synchronize their movements in order to pool their strength. More complex examples of *goal-directed* interpersonal action synchronization are rowing, dancing, or making music. During these and similar activities, synchronizing actions with others serves as a means to reach a shared goal. Here, individuals control their actions and actively strive for synchronization. Synchronized actions show a wide range of characteristics: For example, they can be performed either simultaneously (e.g., singing in unison) or alternatedly (e.g., boxing). They can also differ with respect to the actions performed by each individual: When two individuals dance together, one dancer may spin while the other dancer may walk forward. Furthermore, actions of two individuals that are time-shifted but closely aligned with each other in time (e.g., audience waves in a stadium) are described as synchronized, too. In general, hardly any social interaction is possible without coordinating activities very precisely on a temporal dimension. In the present study, the focus will mainly be on goal-directed simultaneous synchronization between two individuals (i.e., within dyads).

Thus, I propose that synchronization processes can be characterized along two dimensions as (a) individual versus interpersonal and (b) not requiring intention (abbreviated to "non-intentional" in the following) versus goal-directed. Table 1.1 summarizes examples of different synchronization processes described in the literature. A general experience is that we automatically adjust our behavior to environmental rhythms. For example, a natural response to music is non-intentional synchronization of body movements to the rhythm (e.g., Chen, Zatorre, & Penhune, 2006; Large, 2000; Eerola, Luck, & Toivainen, 2006; Snyder & Krumhansl, 2001). This kind of non-intentional individual synchronization (Table 1.1, Cell A) often occurs spontaneously and without much effort: We start swaying or synchronize our movements with the music. Furthermore, there is extensive research on goal-directed individual action synchronization (Table 1.1, Cell B). Studies in this context have focused on individuals' action regulation mechanisms and timing abilities with mechanical time keepers (e.g., Aschersleben & Prinz, 1995; Krampe, Mayr, & Kliegel, 2005; Wing & Kristofferson, 1973). Quite a few studies investigated behavioral synchronization processes that are not necessarily accompanied or triggered by the intention to coordinate, including some selected developmental aspects herein (Table 1.1, Cell C). Research in this field covers, for example, the investigation of neonates synchronizing their movements with vocal patterns of adults, as well as unnoticed imitation and mimicking between two or more individuals during communication processes (e.g., Condon & Sander, 1974a, 1974b; van Baaren, Holland, Kawakami, & van Knippenberg, 2004). To my knowledge, however, there is almost no research on goal-directed interpersonal action synchronization, that is, individuals synchronizing with each other without a mechanical time keeper as a means to reach a shared goal (Table 1.1, Cell D).

Table 1.1
Exemplary Research on Behavioral Synchronization

	individual	**interpersonal**
non-intentional	**A** synchronized movements with music (e.g., Large, 2000)	**C** applause (e.g., Neda et al., 2000) parent–infant interaction (e.g., Condon & Sander, 1974a, 1974b; Feldman, 2007) mimicking (e.g., van Baaren et al., 2004)
goal-directed	**B** action regulation (Prinz, 1997) timing (e.g., Aschersleben & Prinz, 1995; Krampe et al., 2005)	**D** ?

Findings that interpersonal behavioral synchronization occurs very early in infancy and holds an adaptive function in many different goal-directed interaction processes throughout the lifespan suggest that research in this area is needed. It was therefore the aim of this dissertation to investigate the developmental antecedents of goal-directed interpersonal action synchronization.

More specifically, I focused on how individuals' develop the ability to synchronize with each other from childhood to older adulthood. This study tested theoretical assumptions on underlying mechanisms of this development and possible individual short-term consequences. Dyads (i.e., two individuals) were investigated as the smallest possible unit in interpersonal contexts.

1.2 Developmental Aspects of Interpersonal Action Synchronization

In the following sections, I will first review research on non-intentional interpersonal behavioral synchronization, and respective developmental aspects. Research on synchronization processes suggests that non-intentional interpersonal behavioral synchronization occurs very early in development. It has further been proposed that synchronization with others is a necessary precondition for many developmental outcomes in infancy, such as parent–child attachment, socio-emotional competencies, and cognitive functioning (e.g., Condon & Sander, 1974a, 1974b; Harrist & Waugh, 2002). It is also known that interpersonal action synchronization later on still plays a key role in social interactions in general (e.g., Richardson, Dale, & Kirkham, 2007; Warner, 1992). Action synchronization is implemented as a means to reach specific interaction outcomes. Second, I will summarize few existing studies that can be associated with characteristics of goal-directed interpersonal action synchronization to finally come to the main interest of the present investigation: the *development* of goal-directed interpersonal action synchronization.

1.2.1 Non-Intentional Interpersonal Synchronization

I refer to automatic synchronization of behavior patterns between two or more individuals that are not triggered by a specific intention as *non-intentional interpersonal synchronization* (see also Table 1.1, Cell C). This kind of synchronization process already occurs in early childhood and can be found in a wide range of different interpersonal situations throughout the lifespan. Research on non-intentional interpersonal synchronization has primarily examined synchronization of vocal and non-vocal behaviors between two or more individuals (e.g., observation of conversations). Detected rhythmic structures in communication processes suggest a strong coupling of events in time, even though they do not necessarily occur simultaneously (i.e., without a time lapse). In this context, it is important to point out that in natural interaction processes, single activities or units of activities are sometimes time-shifted, but still closely aligned in time. By definition, interpersonal behavior that is temporally aligned with each other (i.e., show reciprocally predictable time patterns) is classified as synchronized. Communication research therefore often describes temporal patterns between vocal expressions or body movement (e.g., imitation of postures, gesture, or speech patterns) as *interactional synchrony* or *synchronic imitation*.

Non-intentional interpersonal synchronization already occurs very early in development, for example, various body movements of neonates were found to be synchronized to their parents' vocal statements (for review, see Feldman, 2007; e.g., Bernieri, Reznick, & Rosenthal, 1988; Censullo, Lester, & Hoffmann, 1985; Condon & Sander, 1974a, 1974b; Crown, Feldstein, Jasnow, Beebe, & Jaffe, 2002; Dowd & Tronick, 1986; Koester, Papoušek, & Papoušek, 1989; Lester, Hoffman, & Brazelton, 1985; Peery, 1980). The adaptation to temporal patterns has been characterized as one of the initial steps in the socialization process (e.g., Arco & McCluskey, 1981). Early interpersonal synchronization serves an important developmental function: Coordinated movements and rhythmic patterns in interaction processes facilitate the predictability of future behavior and thus reduce possible uncertainty in interpersonal processes (Tickle-Degnen & Rosenthal, 1987; Warner, 2002). Non-intentionally synchronized behavior in early developmental stages (e.g., between infants and their parents) has been found to be an important factor in the development of secure attachment and cognitive functioning (e.g., Arco & McCluskey, 1981; Ashton, 1976; Harrist & Waugh, 2002; Isabella & Belsky, 1991; Jaffe, Beebe, Feldstein, Crown, & Jasnow, 2001; Schölmerich, Fracasso, Lamb, & Broberg, 1995; Warner, 2002). In addition, Meltzoff and Moore (1977) described imitative behavior to occur in neonates (12–21 days of age). The authors suggested that mechanisms involved in infant imitation function as a basis for the development of fundamental social cognitive skills, including theory of mind and empathy (see also Meltzoff & Decety, 2003; Meltzoff & Gopnik, 1994).

Non-intentional synchronization continues to play a key role in interpersonal exchange processes throughout the life course. For example, during communication, individuals synchronize with each other rather automatically in their gestures, postures, and facial expressions (e.g., Ashenfelter, Boker, Waddell, & Vitanov, in press; Boker & Rotondo, 2002; Chartrand & Bargh, 1999; Crown, 1991; Richardson et al., 2007; Richardson, Marsh, & Schmidt, 2005; Rotondo & Boker, 2002; Warner, 1992). Similar patterns can be found, for example, in the entrainment of interlocutors' breathing patterns (e.g., McFarland, 2001). Furthermore, interacting individuals tend to coordinate their conversations with respect to pauses and switching pauses across dialogues, their rate of speech, and even syntax. That is, they match each others' vocal time patterns (e.g., Cappella & Planalp, 1981; Jaffe, Feldstein, & Cassotta, 1967; Levelt & Kelter, 1982; Webb, 1969; Welkowitz & Feldstein, 1969, 1970). So far, these phenomena have been classified as mimicry, symmetry, mirroring, or phase entrainment. All these terms refer to the organization of identical movements or speech patterns between individuals on a precise temporal dimension, that is, synchronization. Although there is sometimes conscious awareness or even intentional use of synchronization in communication processes, a great proportion of synchronized behavior is unaware (e.g., van Baaren et al., 2004; Chartrand & Bargh, 1999). There is substantial evidence that humans mimic each other non-intentionally in the situations described above, even when interacting with strangers (for review, see van Baaren et al., 2004; Chartrand & Bargh, 1999; Lakin, Jefferis, Cheng, & Chartrand, 2003).

As mentioned above, synchronization in natural interaction processes can often be found between complex behavior patterns of two or more individuals. Most early research therefore implemented observation methods to examine non-intentional synchronization, for example, during communication. In order to reduce interaction complexity, recent experimental paradigms have been applied to investigate facets of interpersonal synchronization between two individuals (i.e., dyads) in a controlled way. For example, Goodman, Isenhower, Marsh, Schmidt, and Richardson (2005) reported evidence of non-intentional phase entrainment between two individuals in a dyadic rocking chair paradigm. Though the two rocking chairs were manipulated with different attached weights, individuals adjusted their rocking tempo during conversations without being asked to do so. Results from a study on gait alignment during mobile phone conversations indicated that interpersonal synchronization of walking behavior during conversation occurs non-intentionally even if interlocutors could only hear but not see each other (Murray-Smith, Ramsay, Garrod, Jackson, & Musizza, 2007).

Interacting individuals who coordinate their movements in line with the speech or movements of their counterpart signal that they are entrained in their communication and so motivate each other to continue (e.g., Bernieri et al., 1988; Lakin et al., 2003). Synchrony, therefore, can serve a communicative function itself: The level of synchrony at a given moment may indicate the degree of understanding, agreement, or support experienced between individuals (e.g., Lakin et al., 2003). Several studies have shown that mimicry plays an important functional role in social interactions as it increases positive affect, empathy, liking of the interaction partner, rapport, affiliation, and prosocial orientation in general (Lakin & Chartrand, 2003; van Baaren et al., 2004; Warner, Malloy, Schneider, Knoth, & Wilder, 1987). Again, temporal patterns and synchronized movements enhance predictability of future behavior and therefore facilitate interpersonal interactions (e.g., Bernieri & Rosenthal, 1991). In contrast, a disproportionately high amount of synchronization (e.g., exaggerated imitation) can result in negative experience, namely that individuals feel aped or made fun of by their interaction partner (e.g., Warner et al., 1987). Further research on short- and long-term outcomes of non-intentional interpersonal synchronization will be reviewed below.

To summarize, there is empirical evidence that non-intentional interpersonal synchronization occurs very early in development and can then be found in different interpersonal situations throughout the lifespan (e.g., mimicking of movements or speech patterns in communication processes).

1.2.2 Goal-Directed Interpersonal Action Synchronization

In contrast to the non-intentional interpersonal synchronization processes described above, synchronization very often takes place in situations in which individuals aim at reaching a specific goal (i.e., *goal-directed interpersonal action synchronization;* see also Table 1.1, Cell D). For example, Shockley, Santana, and Fowler (2003) made the interesting observation that in comparison to free conversation conditions, even more accurate interpersonal synchronization of posture occurs between dyads who are working on a task together (i.e., a dyadic puzzle). This result supports the observation from everyday experiences that individuals somehow make "use" of synchronized actions when striving for reaching a goal (e.g., Sebanz, 2006). In the following section, I will therefore give an overview of research related to interpersonal action synchronization with a goal-directed function.

The term *action* has been defined as a behavior that is in the service of goals (e.g., Vallacher, Nowak, Markus, & Strauss, 1998). It is therefore necessary to highlight the importance of goals that lead people to synchronize their actions with each other. During natural interpersonal action coordination, individuals' activity is often led by a collective intention that both individuals strive to reach (e.g., Bratman, 1992). In these situations, synchronization processes do not occur non-intentionally, but function as *goal-directed* behavior. For example, when two or more musicians play a piece of music together, synchronizing the instruments in time is often the most efficient way to produce the desired outcome (i.e., *goal*). *Shared intentions* are understood as more than just the sum of individuals' single intentions (e.g., Bratman, 1992; Searle, 1990; Tuomela, 1990): It is not the intention of each musician to only play his or her own part, but to develop a comprehensive sound. Gilbert (1996) states that if "a goal has a plural subject, each person has offered his will to be a part of a pool of wills that is dedicated, as one, to that goal" (p. 185). Even in an antagonistic or competitive exchange, such as a competition between two teams, one team needs to coordinate with the other in the goal to compete (Marsh, Richardson, Baron, & Schmidt, 2006). Marsh and colleagues proposed that "pressure from the environment (i.e., the need to complete some goal) provides the increase in energy that allows patterned movements to emerge … out of previous random movement" (2006, p. 6–7).

Goals can either be implied by the situation (e.g., two individuals moving a table together) or are explicitly formulated (e.g., orchestra instructed by a conductor; Rasmussen, 1983). So far, research on goal-directed action synchronization has mainly focused on individuals' basic synchronization abilities (see also Table 1.1, Cell B). One example is the ability to coordinate our actions in time to coincide with an external event, that is, *perception–action coupling*. This competency is a feature of many everyday activities, from pressing a key on a piano or hitting a squash ball (e.g., Summers, 2002). I will provide a more comprehensive review of research on individual goal-directed action synchronization later on. Here, the focus will be on goal-directedly synchronized actions *between two or more individuals*. However, only very few studies have included conditions in which individuals were asked to synchronize with each other (i.e., goal-directed interpersonal action synchronization); none of them has examined developmental aspects. In the following, I will therefore summarize theoretical considerations in the broader context of goal-directed interpersonal action synchronization and review the limited research that has approached the phenomenon more specifically.

So far, only a very small number of studies have examined goal-directed interpersonal action synchronization between two individuals at all. Theoretical considerations refer to identical mechanisms underlying goal-directed individual and interpersonal action synchronization (e.g., Bourbon, 1990; Helmuth & Ivry, 1996). Most research including interpersonal conditions in goal-directed synchronization tasks aimed at investigating differences between, for instance, individual bimanual and interpersonal action synchronization. Research paradigms comprised both discrete (e.g., finger-tapping) and continuous (e.g., leg-swinging) synchronization tasks. For example, results indicated that when individuals performed goal-directed synchronization tasks with both hands at the same time, synchronization accuracy increased relative to the single-movement case. It was therefore hypothesized that as compared to individual goal-directed synchronization, the accuracy would also be higher when two different individuals produce each of the movements (i.e., interpersonal action synchronization). However, empirical evidence does not support this hypothesis (e.g., Helmuth & Ivry, 1996; Mechsner & Kerzel, Knoblich, & Prinz, 2001; Mechsner & Knoblich, 2004). In fact, in *continuous* limb-synchronization tasks (e.g., leg or pendulum swinging), strength of interpersonal inter-limb coupling (e.g., two individuals synchronize their swinging legs to a metronome) was even found to be weaker than inter-limb coupling within individuals (e.g., one individual swings both legs synchronized to a metronome; Schmidt, Bienvenu, Fitzpatrick, & Amazeen, 1998; Schmidt & Turvey, 1994). These findings suggest that mechanisms underlying individuals' synchronization with a mechanical time keeper may be theoretically similar but not identical compared to the interpersonal mode, that is, two individuals synchronizing with each other.

The focus of this dissertation was on the synchronization of *discrete* movements between two individuals. To my knowledge there are only three studies that have investigated goal-directed interpersonal action synchronization of this kind, where two participants were instructed to synchronize finger movements with each other (Helmuth & Ivry, 1996; Mates, Radil, & Pöppel, 1992; Oullier, de Guzman, Jantzen, & Kelso, 2003). Similar to research on continuous synchronization (e.g., Schmidt, Carello & Turvey, 1990; Schmidt, Christianson, Carello, & Baron, 1994; Schmidt et al., 1998; Temprado & Laurent, 2004), in all studies on discrete synchronization behaviors, participants were instructed to synchronize their actions with each other and an additional mechanical time keeper. That is, at least one of the partners synchronized to a metronome while the second partner synchronized with the actions of the former. Only one study by Oullier et al. (2003) provided first empirical evidence for more stable interpersonal synchronization between participants' index finger-flexion when the external pacing information was switched off: One participant was instructed to synchronize finger movements to a metronome, while the other participant had to synchronize finger movements with the first participant without hearing the metronome. Results indicate that stronger mutual entrainment was possible when the first participant was no longer provided with external timing information.

In contrast, I assume that in *natural interactions*, individuals function as each others' time keepers. These need to adjust reciprocally to reach a shared goal. During interaction processes, endogenous oscillators in the brains of the interaction partners are proposed to become mutually entrained (e.g., Wilson & Wilson, 2005). Endogenous oscillators are populations of neurons with periodic activity. This implies a timing–related function. Across a wide range of physical systems (e.g., electrons, pendulums etc.), oscillators that are allowed to influence each other tend to become non-intentionally phase-locked (e.g., Heckscher, 1913). For example, in research on individuals' timing abilities, it is proposed that each individual has an inherent rate of activity, the so-called *preferred tempo*, which is assumed to be determined by biological factors (e.g., arousal) as well as by the environment (e.g., noise; Boltz, 1994; Frischeisen-Köhler, 1933a, 1933b), and which seems to be relatively stable over medium periods of time (Provasi & Bobin-Bègue, 2003; Vanneste, Pouthas, & Wearden, 2001). During many synchronization processes, interactants need to adjust their internal states (e.g., preferred tempi) with each other to enhance the probability of achieving synchronization with their interaction partners, that is, to reach a shared goal (e.g., Nowak et al., 2005). Interpersonal action synchronization can thus be understood as bidirectional entrainment between two or more interaction partners (e.g., Haken, Kelso, & Bunz, 1985; Schmidt, Richardson, Arsenault, & Galantucci, 2007). The aim of the present study was to investigate age-differences in goal-directed dyadic synchronization, that is, individuals adjusting their actions to each other to become synchronized. Therefore, individuals were instructed to synchronize with each other without an external time keeper.

To conclude, a small number of studies on goal-directed synchronization included interpersonal conditions, in which two or more individuals were instructed to synchronize together towards a specified frequency provided by a mechanical time keeper. In general, individuals show lower synchronization accuracy when synchronizing together with another person than in unimanual and bimanual individual synchronization conditions. In contrast, the present study investigated goal-directed interpersonal action synchronization as occurring between two individuals and without control of external time keepers.

In the previous sections, I reviewed research evidence indicating that interpersonal synchronization occurs non-intentionally very early in development and is an important facet of various interaction processes throughout the lifespan. It serves important developmental functions and is involved in almost all social situations, for example, in the context of attaining a shared goal. However, no research thus far has investigated age-related differences in the ability to synchronize one's actions with those of others to achieve a shared goal. Directly referring to this gap in research, the present dissertation aimed at investigating the development of goal-directed interpersonal action synchronization across the lifespan, with a main focus on its individual antecedents and consequences. In the following section, I will therefore embed the present research into *theories of lifespan development* (e.g., P. B. Baltes, Lindenberger, & Staudinger, 2006).

1.3 Interpersonal Action Synchronization in the Context of Life Mechanics and Life Pragmatics: A Lifespan-Theoretical Framework

In order to investigate the development of interpersonal action synchronization across the lifespan, I closely relate the main theoretical considerations of the present study to some of the key concepts of *lifespan developmental theory* (e.g., P. B. Baltes, 1987, 1990; P. B. Baltes et al., 2006). In the following section, I will develop a *theoretical framework of lifespan development of goal-directed interpersonal action synchronization* that is closely linked to these concepts.[1]

[1] The introduction of the key concepts does not claim completeness, but exclusively focuses on selected definitions related to the theoretical framework of the present study.

1.3.1 Key Concepts of Lifespan Psychology

Ontogenetic human development, as proposed by P. B. Baltes (1987), is a *life-long process*. One goal of research in lifespan developmental psychology is to describe general principles of life-long development. At all stages of the lifespan, different continuous and discontinuous processes are proposed to play a role in development, as stability and change in behavior is evident throughout the life course (e.g., P. B. Baltes, 1987; P. B. Baltes et al., 2006). As described in previous sections, there are indications for various forms of interpersonal action synchronization throughout the lifespan. Interpersonal action synchronization already occurs very early in infancy. In all following life phases, the ability to synchronize one's own actions with those of others seems to be crucial for social engagement and numerous interaction processes. As I will discuss in more detail later, there is also evidence for short-term as well as long-term consequences of interpersonal action synchronization (e.g., positive affect, development of social cognitive competencies). The development of the ability to synchronize with others to reach a certain goal can thus be understood as a life-long process.

Lifespan development is further proposed to be *multidimensional*. That is, several subcomponents are involved in the development of specific domains (e.g., sensorimotor, self and personality). In general, development within each domain has been suggested to be driven by two components: *life mechanics* and *life pragmatics* (Schindler & Staudinger, 2005; Staudinger & Pasupathi, 2000). Life mechanics are described as the "hardware" or basis of development, that is, biology-based and content-poor patterns of, for example, sensorimotor functioning. Life pragmatics comprise declarative and procedural knowledge about the world and the self, shaped by cultural contexts and individual choices. The theoretical separation of the two components does not mean that they function as independent or clearly dissociable factors. Rather, the interaction between the two is considered to function as a basis for individuals' behaviors. This juxtaposition has first been described in the context of intellectual development as mechanics and pragmatics of cognition (e.g., P. B. Baltes, 1987, 1997; P. B. Baltes, Staudinger, & Lindenberger, 1999; Lindenberger, 2000). For example, in cognitive lifespan development, *cognitive mechanics* refer to basic cognitive operations (e.g., information processing), which are closely related to biological (e.g., neurophysiological) conditions (P. B. Baltes et al., 2006). In contrast, *cognitive pragmatics* concern the knowledge-based and context-related application of these basic skills (e.g., P. B. Baltes, 1987; P. B. Baltes et al., 2006). Pragmatic skills are acquired during ontogeny, for example, in the context of cultural and socialization events. Likewise, I assume that interpersonal action synchronization also depends on the development of mechanical (e.g., perception, motor reaction) and pragmatic competencies (e.g., experience-based knowledge about the self and others' actions).

The direction of developmental change can differ, between as well as within life mechanics and pragmatics (*multidirectionality*; P. B. Baltes, 1987; 1990). That is, development is not bound to one single criterion of growth or increase. The theoretical distinction between life mechanics and life pragmatics is partly supported by empirical evidence for divergence in the respective lifespan developmental trajectories in cognitive development (e.g., P. B. Baltes et al., 2006). For example, in the development of cognitive functioning, cognitive mechanics (e.g., information processing) follow an inverse U-shaped function across the lifespan, with a peak in younger adulthood and a decline until older adulthood. In contrast, cognitive pragmatics (e.g., context-related knowledge) continue to increase until younger adulthood and remain relatively stable until old age (e.g., P. B. Baltes et al., 2006; Lindenberger & Baltes, 1997). Similar trajectories are proposed for life mechanics and life pragmatics in general, although empirical support for a broad generalization is lacking so far. In later sections, however, I will provide empirical evidence from previous studies indicating that the respective competencies proposed to be relevant for interpersonal action synchronization follow developmental trajectories similar to mechanics and pragmatics of intelligence.

Another concept of lifespan psychology proposes that development is always based on *gains* (e.g., increase) and *losses* (e.g., decline), that is, no developmental change is pure gain. With this conceptualization, Paul Baltes (1987) aimed at extending the concept of development from the biological conception of growth as a further elaboration of the notions of multidimensionality and multidirectionality. The assumption is that during one developmental period some systems can show an increase while there is a functional decline in others. For example, as described above, mechanics of intelligence show a decline in older age, and the same change can imply both losses and gains depending upon the criteria by which it is judged, while pragmatics of intelligence remain relatively stable or even increase until older adulthood (e.g., Lindenberger & Baltes, 1997). Overall, *successful* development throughout the lifespan is defined as the ongoing process of the person–environment interaction that leads to the maximization of gains and the minimization of losses (e.g., M. M. Baltes & Carstensen, 1996; Freund, Li, & Baltes, 1999). Age-related changes in the gain–loss ratio are expected, because in general, the likelihood of irreversible losses increases with age. The dynamic of positive and negative change has therefore been proposed to be shaped by different regulation processes (e.g., Freund et al., 1999). For example, the meta-theoretical model, S*elective Optimization with Compensation,* captures these underlying processes (e.g., P. B. Baltes & Baltes, 1990; Riediger, Li, & Lindenberger, 2006).

Further lifespan developmental propositions are, among others, *plasticity* (i.e, individuals' potential for different forms of development), *historical embeddedness* (i.e., development varies according to historical-cultural conditions), and *multidisciplinarity* (i.e., lifespan developmental research requires the inclusion of different disciplinary perspectives; e.g., P. B. Baltes, 1987). These concepts are not further explicated here because they do not relate directly to the theoretical model that I will introduce in the next section.

1.3.2 Applying Lifespan Concepts to the Development of Interpersonal Action Synchronization: A Theoretical Model

In this section, I will propose a theoretical model that illustrates how the investigation of the development of goal-directed interpersonal action synchronization is related to lifespan theoretical considerations.[2] It is important to note that the model is highly simplified to allow clear introduction of the theoretical propositions grounding this research. In line with the aforementioned lifespan theoretical concepts, I propose that the competencies underlying the development of goal-directed interpersonal action synchronization can be assigned to the two global components of development, that is, life mechanics (e.g., sensorimotor abilities) and life pragmatics (e.g., knowledge-based competencies).

In close analogy to goal-directed actions in general (Hommel, Müsseler, Aschersleben, & Prinz, 2001), goal-directed interpersonal action synchronization requires individuals' abilities to perceive one's own and others' actions (*sensory system*), predict them (e.g., socio-emotional competencies; based on *social experience*), and continuously react to them (*motor system*). This is necessary to permit successful participation in the ongoing interaction process. In most individual sensorimotor tasks, the body acts as a multivariable continuous control system that synchronizes its movements with the environment. Performance is based on *feedforward control* (i.e., actions are selected based on comparison of actually perceived and anticipated events) and depends upon a very flexible and efficient dynamic internal model (for review, see Decety & Sommerville, 2003). Feedforward control is especially required to allow for rapid coordinated movements (e.g., Rasmussen, 1983). In all situations, individuals are assumed to choose from different action alternatives not only by perceiving but also by anticipating sensory consequences of their own motor commands (i.e., forming *representations*; e.g., Blakemore & Decety, 2001; Decety & Sommerville, 2003; Knoblich & Jordan, 2003; Miall & Wolpert, 1996; Wolpert & Kawato, 1998).

---

[2] If not noted differently, all interpersonal synchronization processes referred to in the following sections are understood as goal-directed.

I propose that similar processes underlie goal-directed interpersonal action synchronization. In the present study, life mechanics therefore pertain to individuals' sensorimotor abilities that are necessary for perception and reaction in the interpersonal context. Life pragmatics in the context of interpersonal action synchronization concern socially-formed skills and experience-based competencies that considerably facilitate anticipation of future events. Individuals' abilities, necessary for the ability to synchronize one's actions with those of others, develop differentially but are interrelated with each other across the lifespan. Hence, they can function as antecedents of individual and age-related differences in the ability to interpersonally synchronize.

In the next sections, I will elaborate on a theoretical framework (see Figure 1.1) that will link the development of goal-directed interpersonal action synchronization and its underlying mechanisms to the key concepts of the lifespan developmental perspective. As explained above, I propose that the development of interpersonal action synchronization is based on competencies pertaining to life mechanics and life pragmatics that change with age. Below, the implementation of the two components with regard to their specific relationship to interpersonal action synchronization will be introduced in more detail. Finally, short- and long-term (i.e., developmental) individual and dyadic outcomes of successful interpersonal action synchronization will be summarized.

1.3.3 Interpersonal Action Synchronization in the Context of Life Mechanics

Life mechanics can be understood as the "hardware" or basis of development. Biology-based and content-poor patterns of, among others, perceptual skills, motor response, and information processing are subsumed under life mechanics (Staudinger & Pasupathi, 2000). In general, interaction processes strongly depend on individuals' abilities to perceive the other person and react appropriately within the given social situation. Hence, I assume that different facets of life mechanics are antecedents of interpersonal action synchronization (see Figure 1.1).

As mentioned above, individuals continuously "choose" from different action alternatives during goal-directed action processes. For individuals, action alternatives are internal, whereas dyads or groups need access to external cues that provide reliable information about the others' action alternatives (Knoblich & Jordan, 2003). This information can be perceived by observing someone else's actions or the respective action outcomes. Therefore, individuals' perceptual skills should be antecedents to the ability to synchronize own actions with others. In individual action synchronization processes, individuals mainly use tactile-kinesthetic feedback of own actions and

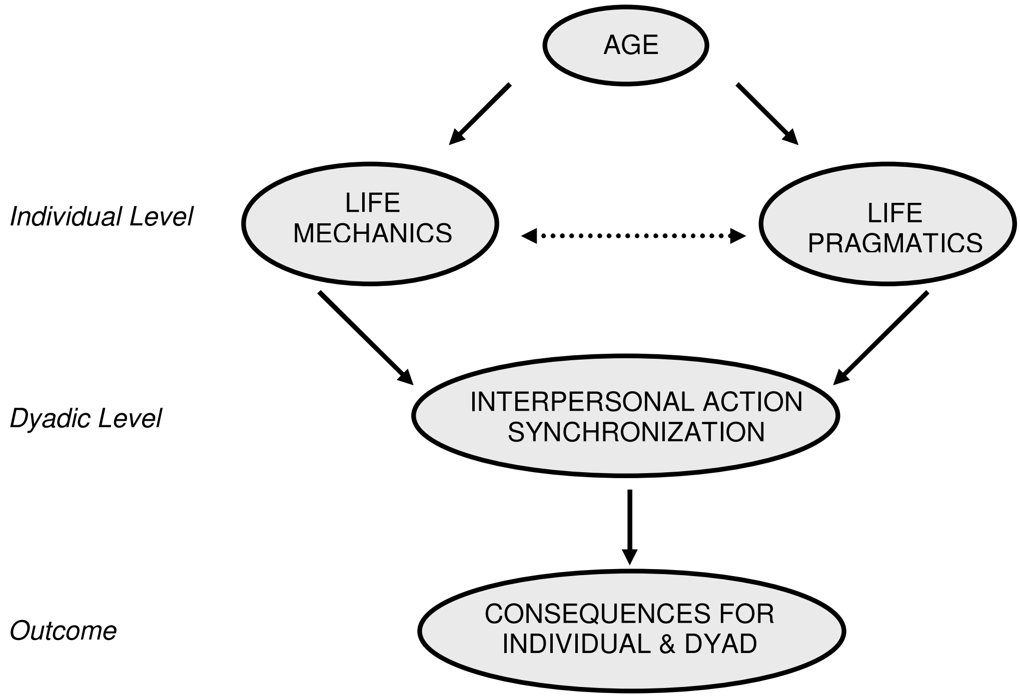

Figure 1.1. Theoretical model of the lifespan development of goal-directed interpersonal action synchronization.

visual and auditory sensory feedback of environmental stimuli to adjust actions in time (e.g., Repp & Penel, 2004; Richardson et al., 2005). In contrast, most dyadic interactions depend on reciprocal exchange: One member of a dyad changes in response to the partner's action while at the same time producing actions that influence the other's behavior (e.g., Tognoli, Lagarde, de Guzman, & Kelso, 2007). Therefore, individuals need to consider feedback from the action of the interaction partner while performing own actions. The basic perceptual skills required for these processes can be assigned to the mechanical component proposed in lifespan developmental theory.

In the same line of argument, a close link between perception and action systems is proposed to be responsible for interaction outcomes (Barresi & Moore, 1996; Jordan & Knoblich, 2004; Knoblich & Jordan, 2002; Sebanz et al., 2006). As perception is not sufficient to regulate coordination processes, especially if fast reactions are needed, Hommel and colleagues (2001) have argued in their *Theory of Event Coding* (TEC) that a common representational medium for coding and storing both perceptual contents and action planning exists. These distal representations support the coordination of actions as well as the anticipation of events (e.g., James, 1890). Most likely, principles of event coding are also relevant to the multiple-person case, as basic perception–action links are crucial for many social interactions (e.g., Knoblich & Sebanz, 2006; Tsai, Kuo, Jing, Hung, & Tzeng, 2006). Hence, in different social situations, interpersonal action coordination is only possible via anticipatory control over the other's action (e.g., Knoblich & Jordan, 2003). For example, when two musicians play a duet, a reaction to the perceived action outcome of the partner would continuously lead to delays in the interaction. In order to play with each other in a synchronized manner, it is necessary to anticipate what the other person will play a few milliseconds later. In other words, joint actions rely on *shared action representations* and the prediction of future events of one's own and others' actions (e.g., Kleinspehn, Li, Müller, Riediger, & Lindenberger, 2005; Knoblich & Sebanz, 2006).

In general, life mechanics are described as following an inverse U-shaped developmental trajectory across the lifespan. Sensorimotor abilities (e.g., perceptual skills, motor reactions) that are implemented in the theoretical framework as antecedents of the development of interpersonal action synchronization are found to follow a similar function: They improve throughout childhood, show a peak in young adulthood, and a decline in older adulthood (e.g., Bloch, 1998; Dempster, 1992; Kail, 1991; Li, Lindenberger, Hommel, Aschersleben, Prinz, & Baltes, 2004; Salthouse, 1984, 1996; Schaie, 1994; Smith & Baltes, 1999; Thelen, 1993). Furthermore, several studies report that an impairment in visual and auditory functioning is associated with limitations in social and communicative activities in old age (e.g., Carabellese et al., 1993; Marsiske, Delius, Maas, Lindenberger, Scherer, & Tesch-Römer, 1999; Tesch-Römer & Wahl, 1996; Weinstein & Ventry, 1982). Sensorimotor abilities that are particularly relevant for synchronization processes have been studied comprehensively as individuals' synchronization abilities with mechanical time keepers. I will further elaborate on these aspects when introducing the hypotheses.

To summarize, these theoretical considerations have led to the general hypothesis that higher functioning in mechanical competencies such as sensorimotor abilities enhances interaction processes. As sensorimotor abilities relevant for interpersonal action synchronization are expected to show lifespan developmental change (i.e., improvement and decline), I assume that age-related differences in this individual antecedent should be highly related to individuals' abilities to synchronize with others.

1.3.4 Interpersonal Action Synchronization in the Context of Life Pragmatics

As described above, individuals experience the necessity to synchronize their actions with those of others in a wide range of different situations in their everyday lives. Therefore, they need to be able to adjust their own behaviors to different individuals across various situations. Being equipped with a perception–action system is not sufficient for this adjustment process. Thus, it requires abilities in addition to those subsumed as life mechanics (Tsai et al., 2006). I expect that knowledge-based competencies influence the ability to synchronize with others. Therefore, development of interpersonal action synchronization should also be dependent on *life pragmatics* (see Figure 1.1). Based on life mechanics, individuals are assumed to accumulate declarative and procedural knowledge about the world and the self (Schindler & Staudinger, 2005). Life pragmatics comprise knowledge as well as regulatory competencies, and are shaped by cultural contexts and individual choices (Staudinger & Pasupathi, 2000). In the following, the focus of attention will be on age-related differences in indicators of life pragmatics regarded as relevant for the development of interpersonal action synchronization.

In the context of life mechanics, it was proposed that individuals need to be aware of their own and others' actions but also to be able to anticipate them. Predictions of future events, especially if they take place in social situations, are not only based on cognitive representation, but also require knowledge-based competencies (e.g., interpersonal evaluation, stereotypic expectations) that develop based on experience gained from social interactions throughout the lifespan. In general, social competencies have mechanic and pragmatic expressions and combine cognitive, emotional, and motor components. It is therefore not possible to explicitly differentiate the mechanic from the pragmatic facets in social competencies (e.g., Blanchard-Fields, 1996). Hess (1994) already stressed the importance of taking into account the interaction between knowledge structures and processing mechanisms in understanding social cognition. However, social cognition subsumes understanding of and constant knowledge about own and others' psychological processes (e.g., thoughts, emotions, intentions), concepts that are construed with regard to interpersonal relationships, and of how and why people react in particular ways in specific situations (e.g., Oppenheimer & de Groot, 1981). Various aspects of social competencies (e.g., knowledge and beliefs about the world) are reported to accumulate and change across the lifespan (e.g., Petermann, Niebank, & Scheithauer, 2004; Silbereisen & Ahnert, 2002; Staudinger & Pasupathi, 2000). How individuals make sense of themselves and others as well as different adaptivity processes in adulthood can therefore be conceptualized as life pragmatics (e.g., Blanchard-Fields, 1996; Fiske & Taylor, 1991). Social competencies in the focus of the present study are thus understood as expressions of life pragmatics.

It is still important to point out that some facets of basic social competencies can also be associated to the mechanic component. For matters of clarity, they will be outlined in the following. For example, basic social skills, such as being able to distinguish between own and others' actions are proposed to underlie interpersonal action synchronization (e.g., Sebanz, Knoblich, & Prinz, 2003). From a developmental perspective, I propose that the ability to synchronize with others increases with the improvement of general social cognitive skills (e.g., perspective taking, reciprocal perspective coordination) that facilitate the prediction of more realistic consequences of social interaction processes (e.g., Flavell, Miller, & Miller, 1993; Yeates & Selman, 1989). For instance, the ability to take another person's perspective increases with age during childhood (e.g., Flavell, Botkin, Fry, Wright, & Jarvis, 1968). *Perspective taking* refers to the ability to understand psychological states and processes of others, such as their thoughts, feelings and wishes. It functions on a cognitive (what does the other person *know*?) and on an emotional dimension (how does the other person *feel*?; Chandler & Greenspan, 1972; Petermann et al., 2004; Silbereisen & Ahnert, 2002) and includes the perception of the others' attributes and of interpersonal dynamics. Depending on the dimension and the complexity of the situation, children develop this ability between three and eight years of age (e.g., Silbereisen & Ahnert, 2002). Chartrand and Bargh (1999) reported that individuals higher in perspective taking non-consciously mimicked the mannerisms of confederates more than those with lower perspective taking skills. Likewise, I propose that being able to take into account the perspective of interaction partners enhances prediction of future events and therefore lead to more synchronized interactions.

Modalities of representing one's own and others' actions range from representations of physical forms, through functional representation, to representation in terms of intention or purpose. They develop successively in the first years of life (e.g., Rasmussen, 1983). Hence, representations of others' actions are not only based on mechanic competencies but are also facilitated by knowledge about other people (e.g., about individuals of different age groups) accumulated through social interactions (e.g., Staudinger & Pasupathi, 2000). Especially with regard to more complex representations, (e.g., inferring others' intentions), experience-based knowledge is proposed to function as a facilitating factor. Being able to represent intentional actions of others is part of what has been introduced in the literature as the development of *theory of mind*, that is, the ability to interpret others' behaviors with regard to underlying mental states (i.e., intentions, beliefs, desires), and to distinguish them from one's own (e.g., Baron-Cohen, 1995; Frith, 1996; Galagher & Frith, 2003; Russell & Jarrold, 1999). Differences in theoretical considerations and contradictory empirical findings with regard to age differences in this socio-cognitive ability can be found in the literature. On the one hand, it has been argued that theory of mind develops during early childhood and remains relatively stable across the lifespan (e.g., Astington, Harris, & Olson, 1988; Silbereisen & Ahnert, 2002). Social skills such as representing the mental states of others are well practiced in old age, resulting in superior theory of mind (e.g., Happé, Winner, & Brownell, 1998). In addition, older adults may even prioritize the processing of social and emotional situations (e.g., Carstensen, Isaacowitz, & Charles, 1999). On the other hand, recent studies provide evidence for age-related change in neural functioning that is mainly evident in the frontal and temporal lobes (e.g., Greenwood, 2000; West, 1996). The fact that these brain regions have been associated with theory of mind (e.g., Apperly, Sampson, Chiavarino, & Humphreys, 2004; Frith & Frith, 2003), suggests that theory of mind may decline with age. Slessor, Phillips, and Bull (2007) were able to partly link this contradiction to differences in task modality (e.g., verbal or visual theory of mind tasks). In general, older adults show impairments in the ability to decode mental states of others compared to younger adults. For simpler tasks, however, such as inferring others' intentions, age-related decline may be less pronounced in older adults.

Within the theoretical model, I propose that theory of mind substantially facilitates the anticipation of others' actions as it enables individuals to understand others' intentions. For accurate anticipation of another person's behavior and its outcome, it is necessary for individuals to infer others' *intentions* (Blakemore & Decety, 2001). Schaffer (1977) states that action patterns of a joint nature cannot appear until infants have mastered the idea of intentionality (see also Tomasello, Carpenter, Call, Behne, & Moll, 2005; Tomasello & Racoczy, 2003). Presumably, intentions begin to generate conscious awareness of specific action processes during very early stages of development. In several experiments, Meltzoff (1995) observed 18-month-olds fulfilling an action that the experimenter failed to complete. Being able to understand the intention of the experimenter, children did not re-enact the action of the adult literally, but finalized the action he intended to carry out. Extending the idea of feedforward control (see above), the sensory consequences of another individual's action are compared with what one's own intentions would have been in the situation. The result of this comparison is then attributed to the other person and used for prediction of future events (e.g., Decety & Sommerville, 2003; Wolpert, Doya, & Kawato, 2003). Based on empirical evidence, Sebanz, Knoblich, Stumpf, and Prinz (2005) discuss the possibility that higher-functioning individuals with autism are able to create representations of own actions (i.e., feedforward control in individual action regulation), but have difficulties in higher-level processing of social information (e.g., interpersonal action synchronization). There are also empirical findings showing that intentions are attributed to person-generated rather than machine-generated actions: As shown by Meltzoff (1995), 18-month-old children correctly inferred the intention of an actor, but did not when a machine demonstrated kinematically similar movements. In the case of adults, Wohlschläger, Haggard, Gesierich, and Prinz (2003) showed that a machine's actions were perceived less correctly than another human's actions, even when the actions were visually identical. This difference may occur because being able to integrate others' intentions facilitates the prediction of future events and enhances successful interaction. The same is true for interpersonal action synchronization processes: In order to be able to adjust interpersonal actions on a very precise temporal dimension, both individuals need to infer the other's intention to define the shared action goal. I assume social cognitive competencies to support this process and therefore enhance the synchronization outcome.

Furthermore, several aspects of social competencies refer to socially acceptable learned behaviors that enable a person to interact effectively with others and to avoid socially unacceptable responses (e.g., Gresham & Elliott, 1984). Among others, this requires the ability to cooperate (e.g., helping, sharing), taking responsibility of and controlling own actions, as well as being able to show empathic concern toward interaction partners (e.g., Gresham & Elliott, 1990). In general, such abilities are developed throughout childhood to enable successful interactions across the lifespan. It is proposed that this development is strongly based on the accumulation of knowledge during social interactions. In the present dissertation, the aspects of social competencies that were investigated as related to interpersonal action synchronization are in essence an expression of experience-based knowledge and are therefore related to life pragmatics. The mechanic facets of social competencies explained above will not be assessed directly but presumably are covered by the applied indicators of life mechanics. Hence, if not noted differently, aspects of social competencies referred to in the following sections are understood as expressions of knowledge-based processes.

The expectation that social competencies are related to the ability to coordinate with others was already stated two decades ago (e.g., Baron & Boudreau, 1987). However, there is not much research that directly examines this hypothesis. To my knowledge, there is only one study linking pragmatic competencies to goal-directed interpersonal action synchronization. In this study on dyadic synchronized pendulum swinging, Schmidt and colleagues (1994) assigned partners to each other according to their score on a social competence scale. They were able to show that dyads with opposite social competence scores, that is, one person with a social competence score above average and one person with a score below average (i.e., *high–low*), showed more continuity in the synchronization process than dyads with comparable scores (i.e., *high–high*, *low–low*). Follow-up analyses indicated that the *Social Control* subscale, which refers to dominance- or leadership-orientation of an individual, accounted for 44% of the variance in synchronization. The equal dominance of homogeneous dyads was assumed to lead to synchronization partners' difficulties in the approximation of preferred frequencies (see Section 1.2.2) in pendulum swinging. Conversely, high-competence individuals (i.e., highly dominant) were more likely to prevail with their own frequency when paired with submissive partners. Although the study was based on a very small sample (18 participants) and again included an additional mechanical factor (varying lengths of the pendulum), which may have influenced the synchronization process, the results indicated that social competencies may play a role in interpersonal action synchronization.

In the following, I will focus on two pragmatic competencies proposed to be associated with interpersonal action synchronization: (a) The ability to flexibly adjust to different individuals in various situations and (b) stereotypic age-related expectancies. The following sections are organized with respect to these competencies, including age-related differences within each of them.

Interpersonal Flexibility

In the context of interpersonal action synchronization, individuals need to be able to adjust their actions to different people across various situations. This requires *interpersonal flexibility* in individuals' behavior patterns. In this line of research, interpersonal flexibility is assumed to be a trait-like ability that allows individuals to adjust their own actions to different individuals and the requirements of different social situations. Interpersonal flexibility is assumed to develop with experience from social situations and can be found in individuals' ability to adjust to different others (e.g., of various age groups). People who are interpersonally flexible and high in basic social skills are reported to be more competent in terms of efficiency and appropriateness to the demands of a wide range of social situations (e.g., Martin & Rubin, 1995; see also Leary, 1957). They are able to adapt their interaction strategies according to the constraints of the situation. For example, if two individuals go for a walk, the experience of taller people walking faster can be taken into account when predicting the specific walking speed to adjust to. Individuals are more or less capable of showing behaviors that are appropriate for the situation (e.g., Paulhus & Martin, 1988). Individuals who know or can predict how the task will develop are able to assign their resources to the "continuous practice of a strategy that has already proved to be useful in the situation" (Canas, Antoli, Fajardo, & Salmeron, 2005, p. 98).

In this context, it is necessary to differentiate interpersonal flexibility as defined in this dissertation from other flexibility constructs described in the literature, such as *spontaneous flexibility, intellectual flexibility,* or *cognitive flexibility* (see also Canas et al., 2005; Canas, Quesada, Antoli, & Fajardo, 2003; Kohn & Schooler, 1978; Schmuck, Müller, & Hohmann, 1998). For example, *cognitive flexibility* is defined as the ability to consider multiple conflicting representations simultaneously (e.g., Jacques & Zelazo, 2005). Research in this field investigates, among others, individuals' abilities to adapt strategies in task-set switching paradigms as one aspect of executive functions (e.g., Kray, Eber, & Lindenberger, 2004; Kray & Lindenberger, 2000; Oberauer, 2005).

In line with theoretical considerations on age-related differences in inhibitory control (e.g., Dempster, 1992), studies report empirical evidence for an inverted U-shaped developmental trajectory of task-switching costs across the lifespan. This can be interpreted as cognitive flexibility showing a developmental increase from preschool childhood until younger adulthood and a decrease in older adulthood thereafter (e.g., Crone, Ridderinkhoff, Worm, Somsen, & van der Molen, 2004; Davidson, Amso, Anderson, & Diamond, 2006; Hasher & Zacks, 1988; Kray, Li, & Lindenberger, 2002).

In contrast to the cited constructs that very much focus on cognitive aspects of flexibility, *interpersonal* flexibility includes social aspects that were not considered in this line of research. I therefore assume different developmental trajectories for cognitive and interpersonal flexibility, which is in line with theoretical considerations on *multidirectionality* in lifespan development (see Section 1.3.1). So far, there are no findings from empirical studies on developmental differences in interpersonal flexibility. As the development of this ability is based on individuals' cumulative experiences from social situations and related to other social competencies, I assume that interpersonal flexibility increases with age. It will probably remain relatively stable until very old adulthood, when loss in physical functioning may involve being less flexible. In other words, I expect that including socially-learned experiences in representation formation, and thus being able to adjust to predicted actions, allows more accurate interpersonal action synchronization.

Stereotypic (Age-Related) Expectations

Social competencies subsume knowledge and understanding of social situations associated with oneself as well as others. "Others" can either be physically present, humans in general, or specific social groups. Theories of ideomotor processes focus on how specific actions of others can selectively influence one's own actions, as can be observed, for example, in mimicry or imitation (e.g., Greenwald, 1970; Prinz, 1997; Sebanz et al., 2003). Actions of others are mentally represented and influence individuals' actions, even when the task does not involve taking the actions of another person into account (Sebanz et al., 2003). In addition to knowledge about other people, individuals acquire knowledge about developmental norms and stereotypes through socialization (Staudinger & Pasupathi, 2000). Several automatized actions are therefore also affected by the activation of concepts (e.g., stereotypes, age-specific attitudes) that might simultaneously activate respective motor codes and affect interaction processes as well (e.g., Bargh, 2003; Bargh, Chen, & Burrows, 1996; Ferguson & Bargh, 2004; Hommel et al., 2001; Marsh et al., 2006). Stereotypic expectations may play a role when future actions are predicted. Stereotypes can facilitate information processing if the respective expectations are appropriate with respect to the specific interaction (partner). For example, an individual could expect his or her older interaction partner to show slow behavior patterns. If this was true, correct reactions based on these expectations could make the adjustment process easier. In contrast, stereotypic expectations that are inappropriate may even complicate interaction processes. For example, Coupland, Coupland, Giles, and Henwood (1988) describe different strategies younger adults use that "over-accommodate" towards older adults, that is, younger adults change their behaviors to adjust to stereotypical expectations about the elderly people's abilities, but not to their true abilities. As interpersonal action synchronization requires the correct representation and prediction of others' actions, I suggest that stereotypic expectations that match the partner's actual behavior are positively related to the synchronization outcome. If a partner's behavior differs from individuals' stereotypic expectations, further adjustment towards this discrepancy is necessary. However, in the present study it was not possible to investigate (a) whether participants' age-specific stereotypes matched the behavior of the specific interaction partner or (b) whether the interaction partners acted in accordance with their own general age-related expectations. That is why the relation between positive and negative stereotypic age-related expectations and interpersonal action synchronization is explored in the present study.

To summarize, the ability to anticipate future actions of one's interaction partners is important for interpersonal synchronization. This involves different aspects of social competencies. Knowledge-based social competencies that I will refer to in the present study are understood as indicators of life pragmatics. Among the most important social competencies relevant in this context are (a) the ability to adjust one's behavior patterns flexibly with respect to different individuals and situations, and (b) the integration of stereotypic age-related expectancies that can be in line with or differ from others' actual behaviors. I hypothesize that individual and developmental differences in these abilities are related to the development of interpersonal action synchronization.

1.3.5 Consequences of Successful Interpersonal Action Synchronization for Individuals and Dyads

In human evolution, individuals who were able to cooperate successfully with others and maintain harmonious group relationships were more likely to be included in groups and therefore more capable of accomplishing activities necessary for survival (e.g., securing food sources, defense; for review, see Lakin et al., 2003; see also Chartrand, Maddux, & Lakin, 2005). From an evolutionary perspective, non-intentional and goal-directed interpersonal synchronization in this regard even have provided a beneficial survival function. Previous sections described the functional influence of accurate interpersonal action synchronization to facilitate the achievement of a shared goal (see Section 1.2.2). Besides objective measures of successful interactions, it is important to highlight aspects of the subjective experience of the interaction and the interaction partner.

Although most of the time individuals are unaware of interpersonal synchronization, slight unexpected delays in temporal patterns (e.g., in long-distance phone calls) can disturb communication processes and their outcomes. Also, differences between individuals' speed of speech can lead to negative feelings in an interaction, including impatience and stress. The phrases being "in synch" with another person or "on the same wavelength," for example, integrate synchronization on a behavioral level, but also the experience of congruence of feelings, moods, and thoughts. Research on non-intentional and goal-directed interaction processes indicates that more accurate coordination outcomes (e.g., synchrony) are related to the experience of more positive affect and a more positive evaluation of the interaction partner (e.g., Kulesza & Nowak, 2003; Warner et al., 1987). During successful interactions, interpersonal action synchronization can therefore support the development of "social glue" (Lakin et al., 2003), which is elementary for individuals' social lives.

Other than short-term consequences that are mostly related to subjective experience in a given situation, there is also evidence that interpersonal timing plays a functional role in individuals' longer-term development. Consequences of interpersonal action synchronization can therefore be differentiated as being short-term (e.g., affect) or long-term (e.g., attachment, development of social cognition), and each will be reviewed successively in the following sections.

Short-Term Effects of Interpersonal Action Synchronization

There is empirical support that well-coordinated interactions are experienced positively. Several studies investigated short-term effects of ordered time patterns in conversation processes (e.g., Warner, 1992; Warner et al., 1987; Welcowitz & Kuc, 1973). Findings indicate that more synchronized interaction patterns were related to more positive affect reported by both individuals and more positive evaluations of the respective interaction partner. A number of studies investigated interactional synchrony as indicators of rapport (e.g., Bernieri et al., 1988; LaFrance, 1979; LaFrance & Broadbent, 1976; Lakin & Chartrand, 2003; Tickle-Degnen & Rosenthal, 1987; Trout & Rosenfeld, 1980). Self-report measures as well as observer ratings suggest that organized temporal patterns are related to achieving rapport in different dyads and groups (e.g., couples, school classes). Experimental evidence obtained by Chartrand and Bargh (1999) indicated that participants who were mimicked by a confederate in a neutral conversation, reported liking the confederate more and having experienced the interaction as more smooth and harmonious than those who were not mimicked. This suggests that interactional synchrony aids the flow of the conversation and allows rapport to develop. Another study on temporal patterns in natural conversations found that dyads showing more temporal congruence in their switching pauses reported more warmth in ratings of partners (Welcowitz & Kuc, 1973).

Kulesza and Nowak (2003) used an experimental coordination task to investigate the effect of coordination accuracy on the subjective experience of the partner. In their study, participants were told that they would work on a navigation task with a partner. In effect, they played with a computer simulation program that manipulated the degree of coordination ability of the alleged other person. Results indicated that more accurate coordination outcomes led to more positive evaluations of the actual partner compared to partners who were perceived as coordinating less. Further experiments by van Baaren, Holland, Steenart, and van Knippenberg (2003) showed that subjective experience of synchronization (even non-consciously) can affect individuals' general prosocial behavior. For example, a confederate waitress received more tips when she mimicked her customers (see also van Baaren et al., 2004). This is in line with the assumption that synchronization is "used" to exchange rapport. In this context, it is also discussed if the ability to coordinate and synchronize one's actions with others' may have a significant effect on outcomes in other professional encounters, for example, between teacher and pupil, physician and patient, or psychotherapist and client (e.g., Bernieri, 1988; LaFrance & Broadbent, 1976). In this regard, the relationship between synchronization and subjective experience is a two-sided story: Synchrony creates affiliation, and in turn affiliation, sympathy, and interpersonal understanding can be expressed through synchrony (Bernieri et al., 1988; Lakin et al., 2003).

Interaction processes can therefore benefit from synchronization between the interaction partners. For example, by synchronizing their movements with other speakers' movements in a conversation, individuals can anticipate more accurately the termination of their vocalizations and adjust the timing of their response (e.g., Bernieri & Rosenthal, 1991). However, Warner et al. (1987) suggested a curvilinear relationship of affect and synchronized actions between interacting partners. Although they could not find clear empirical evidence supporting this proposition, it is important to note that both inadequately low and high degrees of synchronization may disturb interpersonal exchange processes. For example, if one partner overacts in imitation, the interaction partner can be annoyed and experience the respective partner more negatively.

In summary, synchronized actions can enhance the interpersonal experience and facilitate interaction processes. In line with the reviewed empirical research, I expected higher interpersonal action synchronization accuracy to be related with a more positive subjective experience of the interaction partner and the interaction.

Long-Term Effects of Interpersonal Action Synchronization

The present study was a cross-sectional investigation, so it did not allow the examination of long-term effects of interpersonal action synchronization. However, to stress the importance of interpersonal action synchronization for development, the next section will give a short overview of research evidence on the effects of interpersonal action synchronization on developmental outcomes. In the literature, different long-term effects of interpersonal action synchronization are described. Though structure and function of interpersonal action synchronization change across the lifespan, the ability to synchronize own actions with others' may represent a crucial achievement for dyadic relationships that facilitates social, emotional, and cognitive development (e.g., Feldman, 2007; Harrist & Waugh, 2002). As there is not much research on long-term effects in adulthood, the following sections summarize selected examples on the relevance of interpersonal synchronization for development of (a) *attachment*, (b) *social cognition*, (c) *personality*, and (d) *language* in children.

Attachment. Empirical evidence as reported by Isabella and Belsky (1991) indicated that infant–mother dyads who were found to interact in a well-timed and synchronous manner at three and nine months of age show a secure attachment style (see also Isabella, Belsky, & van Eye, 1989; Jaffe et al., 2001; Warner, 2002). Here, synchrony in this sense is understood as interactive experience reflecting an appropriate match of parent–infant behavior, which is presumed to derive mainly from parental sensitivity. These results go along with theoretical assumptions that secure attachment is expected to develop when parents interact with their children in a consistent and predictable manner (e.g., Ainsworth, Blehar, Waters, & Wall, 1978). As explained above, interactional synchrony, as a consistent temporal pattern of behavior, can facilitate the prediction of future events. Non-intentional interpersonal synchronization between infants and parents may therefore be interpreted as *one* behavioral antecedent to enhance attachment quality on a micro-level of the parent–infant interaction.

Social cognition. Asendorpf and Baudonnière (1993) proposed that synchronic imitation in preverbal communication between 19-month-old children is related to self- and other-awareness, and function as a basis for the development of perspective-taking abilities and theory of mind.

They reported findings that children who showed mirror self-recognition (as an early form of social cognition) engaged in longer phases of synchronic imitation than children who did not recognize themselves. The authors suggested that self-awareness develops in parallel with synchronic imitative behavior as an antecedent of other-awareness (e.g., self-consciousness, empathy, cooperation), but so far there has been no consistent empirical support for this theoretical assumption (see also Asendorpf, Warkentin, & Baudonnière, 1996; Gopnik & Meltzoff, 1994; Nielsen & Dissanayake, 2004). However, Nadel (2004) stated that the use of the imitative system, via the action recognition mechanism, prepares the understanding of others' intentional actions. For example, imitation of facial movements at an early age has been discussed as a "starting state" for social cognition (e.g., Meltzoff & Gopnik, 1994). This underlines the importance of imitation in socio-cognitive development.

Personality. It is suggested that self-awareness and self-concepts develop hand in hand with other-awareness and concepts of others (Gopnik & Meltzoff, 1994). As individuals do not develop solitarily but in various social contexts in which rhythmic and temporal patterns are immanent features, Nowak et al. (2005) argue in their dynamical-systems approach that personality development also depends on temporal structures in interaction processes. The authors' definition of interpersonal synchronization is somewhat broader than interpersonal action synchronization as focused on in the present study. It includes complex forms of synchronization that reflect nonlinear relationships between partners' actions, thoughts, and feelings. However, the theoretical considerations need to be mentioned in the context of long-term effects of interpersonal action synchronization. Nowak et al. propose that individual differences in personality are shaped by the history of social interactions in which individuals adjust their internal states (e.g., emotions, attitudes) to reach higher interpersonal synchronization accuracy. For example, attunement between individuals' feelings is also described as synchronization. Depending on how synchronization processes are maintained over time, the associated internal states become engraved in the cognitive-affective system and operate as basic settings for subsequent interactions (i.e., become trait-like). An example could be that children who carry out specific behaviors or experience emotions in successful (i.e., synchronized) interactions with their parents, will, in the long run, assign this behavior or emotion to various other situations as well. However, the basis for these considerations is exclusively theoretical so far and needs to be further supported by empirical evidence.

Language. In the development of language skills, rhythm and synchrony perception and production are proposed as precursors of language and therefore facilitate its development (e.g., Condon & Sander, 1974b; Wylie, 1985). Speech rhythms facilitate entrainment, imitation, and reproduction of language (e.g., Couper-Kuhlen, 2001). Likewise, children suffering from dyslexia, for example, show deficiencies in the ability to synchronize their movements with their own speech rhythms (Condon, 1982).

To conclude, there is empirical evidence for a variety of long-term effects of interpersonal action synchronization, for example in the development of (a) attachment between parents and children, (b) social cognitive aspects (i.e., self- and other-awareness), (c) personality, and (d) language skills. Although modalities of interpersonal action synchronization processes differ, the ability to synchronize with others is important for social, emotional, and cognitive development.

1.3.6 Summary of Theoretical Assumptions on Goal-Directed Interpersonal Action Synchronization

In this section, the concept of synchronization, with a focus on goal-directed interpersonal action synchronization, was introduced. Besides highlighting empirical research in this context, a theoretical model of the lifespan development of interpersonal action synchronization was proposed (see Figure 1.1). The main assumptions derived here were (a) that interpersonal action synchronization develops in relation to individual and age-related differences in mechanic and pragmatic factors and (b) that synchronization accuracy is related to personal experiences of the partner and the interaction process.

The main aim of the present dissertation was the investigation of the lifespan development of goal-directed interpersonal action synchronization (i.e., from younger childhood to older adulthood), focusing on its individual antecedents and consequences. To place a focus on the smallest possible unit in interpersonal situations, the empirical investigation was based on synchronization between two individuals, that is, *dyads*. For that purpose, I propose a *dyadic drumming paradigm*. With this paradigm it is possible to investigate individuals of different ages (i.e., 5, 12, 20–30, and 70–80 years) paired to form same-age and mixed-age dyads. In the following section, I will introduce the rationale underlying the paradigm and discuss its advantages in comparison to other paradigms that have been employed in synchronization research so far. To point out how the theoretical considerations were implemented in the present investigation, I will subsequently derive a working model from the theoretical model. With this model, I will further specify the hypotheses that were tested.

1.4 The Dyadic Drumming Paradigm

In order to investigate the development of goal-directed interpersonal action synchronization between two individuals (i.e., *dyadic action synchronization*), it was necessary to find an experimental paradigm that mainly meets four criteria: (a) the complexity of the synchronization task should be reduced as much as possible to control for factors that influence natural synchronization processes, (b) it should be possible to specify the goal to synchronize with each other, (c) the synchronization accuracy between two individuals should be measurable directly during the interaction process, and (d) the paradigm should be applicable for the whole age range of interest, that is, for younger children as well as older adults. The newly developed *dyadic drumming paradigm* meets these requirements. The development of this paradigm closely followed information obtained from research using variants of the so-called *tapping paradigm*. In the following section, I will therefore first briefly outline previous research that utilized tapping paradigms, and based on this, describe the development of the new dyadic drumming paradigm.

1.4.1 The History of Tapping Paradigms

Tapping studies have a long tradition in experimental psychology (e.g., Dunlap, 1910; Fraisse, 1980; Wing & Kristofferson, 1973; for overview, see Aschersleben, 1994, 2002; Repp, 2005). Whereas early research investigated individuals' speed in morse key tapping, tapping paradigms have more recently been employed to investigate individuals' abilities to synchronize to a mechanical stimulus (e.g., a metronome). This mainly relates to research on goal-directed *individual* action synchronization (Table 1.1, Cell B). However, action synchronization processes between two individuals have not yet been examined with these paradigms. The following section will therefore review theoretical assumptions and empirical evidence with respect to individual action synchronization investigated with tapping paradigms.

The main interest of individual synchronization research was on the relationship between perception and action: In *synchronization* conditions, individuals were typically asked to synchronize their finger tapping with a specific metronome frequency. The complexity of naturally occurring sensory and motor processes are minimized by focusing on synchronization as a temporal coupling between movements and movement sequences (e.g., taps) to external events (e.g., metronome-clicks; Drewing, Aschersleben, & Li, 2006). It was found that, on average, taps tend to precede clicks by a few tens of milliseconds, rather than being distributed symmetrically around the tone onsets (e.g., Dunlap, 1910). The *Paillard-Fraisse hypothesis* (Fraisse,

1980) attempts to explain this phenomenon. According to this hypothesis, the synchronization task is performed by integrating the auditory code of the click and the tactile-kinesthetic code representing the tap. These two central codes need to be synchronized in time in the brain, but are subject to different processing times. Therefore they do not coincide in time, and the tap leads over the click (i.e., *negative asynchrony*; e.g., Finney & Warren, 2002; Fraisse, 1980; for discussion, see Aschersleben & Prinz, 1995). I will provide a short overview of the general findings of tapping studies in the following. Although not all findings were of the same importance for the development of the dyadic drumming paradigm, the summary may convey a sense of the flexibility and general advantages of the tapping paradigm as such. Further empirical evidence especially on developmental aspects of individual synchronization and timing abilities will be reviewed in the introduction of the hypotheses.

Some studies focused on the question whether individual synchronization differs with regard to the *nature of the external stimuli* used. Indeed, it could be shown that synchronizing with auditory stimuli (e.g., a metronome) is more accurate than synchronizing with visual stimuli (Bartlett & Bartlett, 1959; Repp & Penel, 2004).

Comparing single-hand with *bimanual tapping*, variability of each single hand was found to be reduced when subjects performed synchronization tasks with both hands (e.g., Drewing & Aschersleben, 2003; Drewing, Hennings, & Aschersleben, 2002). This may be due to additional sensory and tactile-kinesthetic reafferences provided by the second hand (Drewing et al., 2002; Mechsner & Knoblich, 2004). In general, individuals prefer spatial and perceptual *symmetry* (Kelso, 1984; Schmidt, et al., 1990; Schmidt et al., 1994; Schmidt & Turvey, 1994), independently of which muscle is involved in the synchronized action (Mechsner et al., 2001). A model that is often used to explain inter-limb coordination, the *Haken-Kelso-Bunz Dynamic Model* (HKB; Haken et al., 1985; Kelso, 1984; see also Temprado, Zanone, Monno, & Laurent, 1999) posits two competing coordination attractors, one in-phase (symmetric movements) and the other anti-phase (alternate movements). Studies found in-phase coordination to be more stable than anti-phase coordination. In addition, increasing frequencies have been reported to result in decreasing stability of performance (e.g., Forrester & Whitall, 2000; Riley, Santana, & Turvey, 2001; Schmidt et al., 1990; Temprado & Laurent, 2004) and very high frequencies cause an unavoidable switch from anti- to in-phase patterns. That is, individuals find it easier to act simultaneously with each other than alternately.

Another aspect investigated with the tapping paradigm is individuals' *preferred tempo*. It is assumed that each individual has an inherent rate of activity, supposedly determined by biological factors (e.g., arousal) as well as by the environment (e.g., noise; Boltz, 1994; Frischeisen-Köhler, 1933a, 1933b), which seems to be relatively stable over medium periods of time (Provasi & Bobin-Bègue, 2003; Vanneste et al., 2001). Most studies in this line of research asked participants to tap a stable frequency that seems the most comfortable to them (Boltz, 1994; Drake, Jones, & Baruch, 2000; Provasi & Bobin-Bègue, 2003). Fraisse and Oléron (1954) already suggested that individuals' preferred tempo should be related to chronological age. The few empirical studies conducted so far support this assumption: Preferred tapping rates are found to slow down with increasing age (e.g., Drake et al., 2000; Vanneste et al., 2001). It is further postulated that specific personal tempi are apparent in many recurrent processes (e.g., feelings, physical movements, thoughts, rate and rhythm of language) and that there is a comfort range of tempo within which the individual functions most effectively (e.g., Chapple, 1970; see also Frischeisen-Köhler, 1933). This means that when individuals engage in social interactions, their activity cycles are disrupted or modified. I propose that if interaction partners have different tempi or vary in their stability of temporal patterns of performance, their "internal clocks" influence each other. Individual adjustment is therefore necessary to match one's own temporal activity with tempo and variability of others' activities. This adaptation process has been described broadly by Kir-Stimon (1977) in his concept of *tempo-stasis*, which states that individuals always need to keep their own tempos in balance with those of others and the environment (see also Boker & Graham, 1998).

To summarize, tapping paradigms are an approved method that meet the requirement of minimal complexity in the investigation of synchronization processes. It can therefore be flexibly adjusted to a wide range of research questions related to synchronization. The reviewed theoretical considerations and empirical evidence were taken into account in the further development of the tapping paradigm into a drumming paradigm, which will be introduced in the following section.

1.4.2 From Individual Tapping to Dyadic Drumming

Although it has a long research tradition, to date the tapping paradigm has only been used in a very limited number of studies on goal-directed interpersonal action synchronization and not at all in research on the underlying mechanisms of development. Some studies have included dyadic movement conditions to investigate whether similar or even identical regulation processes underlie individual synchronization with an external stimulus and action synchronization between two or more individuals (e.g., Bourbon, 1990; Helmuth & Ivry, 1996; Oullier et al., 2003; Tognoli et al., 2007). A small number of studies have also employed dyadic tapping conditions, but all of them examined dyadic synchronization with an additional mechanic time keeper. In contrast, the focus of the present study was on goal-directed action synchronization between two individuals, that is, dyads were instructed to synchronize with each other without reference to an external stimulus.

Therefore, I propose an adaptation of the tapping paradigm that allows the investigation of the development of goal-directed interpersonal action synchronization in a very controlled way: the *dyadic drumming paradigm*. In this paradigm, two individuals are instructed to synchronize their drumming (i.e., with drumsticks) with each other at a frequency they both feel comfortable with. That is, in a free dyadic condition, no external mechanical time keeper (e.g., metronome) is applied because individuals are expected to act as time keepers for each other. Given individual differences in tempo and stability of individuals' temporal activity, a natural reciprocal adjustment process between both partners' temporal patterns of performance is expected, as temporal characteristics from one individual are capable of modifying or being modified by the temporal patterning of the interaction partner (e.g., McGarva & Warner, 2003; Welkowitz & Feldstein, 1969).

The first important advantage of the dyadic drumming paradigm is that it minimizes the complexity of the synchronization process as compared to, for example, observation during natural interactions. Nevertheless, it still allows for the investigation of natural adjustment processes that appear between individuals when synchronizing with each other to reach a shared goal. The dyadic or shared goal is implemented into the situation by explicitly instructing individuals to synchronize with each other. Furthermore, it is possible to directly measure the synchronization process based on the synchronized movements throughout the situation.

Another central advantage of the dyadic drumming paradigm is its applicability to different age groups (i.e., children as well as adults). In general, I propose to use drumming other than tapping if the main interest is on developmental differences in interpersonal action synchronization for two reasons. First, rather long synchronization sequences are necessary to investigate interpersonal action synchronization. I expect that maintaining synchronized movements is easier to keep up when drumming (i.e., using forearm movements) as compared to tapping (i.e., finger movements). Second, there is empirical evidence for a decline in sensorimotor functioning in older adults, specifically in fine motor skills, which are more relevant in tapping than in drumming (e.g., Holle, 1988; Jagaczinsky, Greenberg, Liao, & Wang, 1993; Salthouse, 1982, 1984; Shumway-Cook & Woollacott, 2001; Welford, 1977). Using drumming instead of tapping, it is possible to partly control for age-related differences in interpersonal action synchronization due to differences in fine motor functioning.

As reviewed above, findings from research on individual synchronization abilities indicate differences in the nature of stimuli: Synchronization with auditory stimuli has been found to be more accurate than synchronizing with visual stimuli (e.g., Bartlett & Bartlett, 1959; Repp & Penel, 2004). I propose that this also applies to the interpersonal situation, that is, different modes of feedback from the other's action may affect the synchronization process. By using an elaborate experimental setup that I will describe in the Method part, it is possible to control the feedback individuals receive from themselves and from their drumming partner. In the present investigation, I further aimed at controlling for potential age-related differences in the preferred mode of feedback of the partner's actions (e.g., children may integrate feedback channels differently than adults). This was possible with the dyadic drumming paradigm as participants only received auditory feedback of their partner's drum beats, that is, they were not allowed to see each other during the synchronization situation. Taken together, the drumming paradigm is an appropriate paradigm for all age groups of interest.

To summarize, the present study used a dyadic drumming paradigm to assess interpersonal action synchronization. This paradigm (a) minimizes the complexity of the synchronization task, (b) permits the specification of the goal within the situation, (c) allows the direct measurement of synchronization accuracy during the interaction process, and (d) can be employed to investigate developmental differences as it is applicable for a wide age range. Hence, in the present study, participants of four age groups (i.e., 5, 12, 20–30-, and 70–80-year-olds) were paired in same- and mixed-age dyads and instructed to synchronize with each other as accurately as possible.

1.5 Research Questions and Hypotheses

The aim of the present study was the investigation of the development of goal-directed interpersonal action synchronization across the lifespan, that is, to find out how individuals' abilities to synchronize with others develop from childhood until older adulthood. I intended to provide insight into individual and age-related aspects of interpersonal action synchronization, that is, differences in individual competencies underlying the ability to synchronize with others as. This ability should thus be observable in interpersonal action synchronization between individuals of same- and mixed ages. In addition, I aimed to examine the effect of the respective synchronization accuracy on individuals' experience. To set a focus on the smallest unit of interpersonal situations, the present investigation was based on dyads (i.e., two individuals synchronizing with each other). That is why *dyadic action synchronization* was investigated as one example of interpersonal action synchronization. (I will use interpersonal action synchronization and dyadic action synchronization interchangeably in the following sections.)

I focused on antecedents as well as consequences of dyadic synchronization. More specifically, the following three research questions were derived from the theoretical framework as a basis for the present investigation:

1. How do individual and age-related differences in sensorimotor abilities and social competencies relate to dyadic action synchronization?
2. Do dyads of varying age compositions differ in dyadic action synchronization?
3. How does the accuracy of dyadic action synchronization affect individuals' subjective experience of the interaction partner and the situation?

In the following, I will introduce a working model that closely relates to the theoretical framework of the development of interpersonal action synchronization as displayed in Figure 1.1. The working model is derived from the theoretical model in order (a) to illustrate how the theoretical assumptions were directly implemented in the present investigation and (b) to specify the research questions and hypotheses that were tested.

1.5.1 Individual Antecedents and Consequences of Dyadic Action Synchronization: A Working Model

Within the theoretical framework of the development of interpersonal action synchronization, the ability to synchronize one's actions with those of others is hypothesized to develop as competencies pertaining to life mechanics and life pragmatics change with age (see Section 1.3). As displayed in the working model, life mechanics in the present study concern individual sensorimotor abilities relevant for the perception of the other person's action and appropriate motor reactions (see Figure 1.2). Beyond that, life pragmatics hypothesized to be related to interpersonal action synchronization comprised different aspects of experience-based social competencies. Being aware of mechanic aspects of social competencies, abilities referred to in the present study are understood as expressions of life pragmatics. Age-related differences in the individual competencies are hypothesized to be related to individuals' abilities to synchronize with others. Therefore, synchronization accuracy is also expected to vary between different age group combinations. As possible short-term consequences on the individual level, the subjective experiences of the partner and the interaction process were investigated.

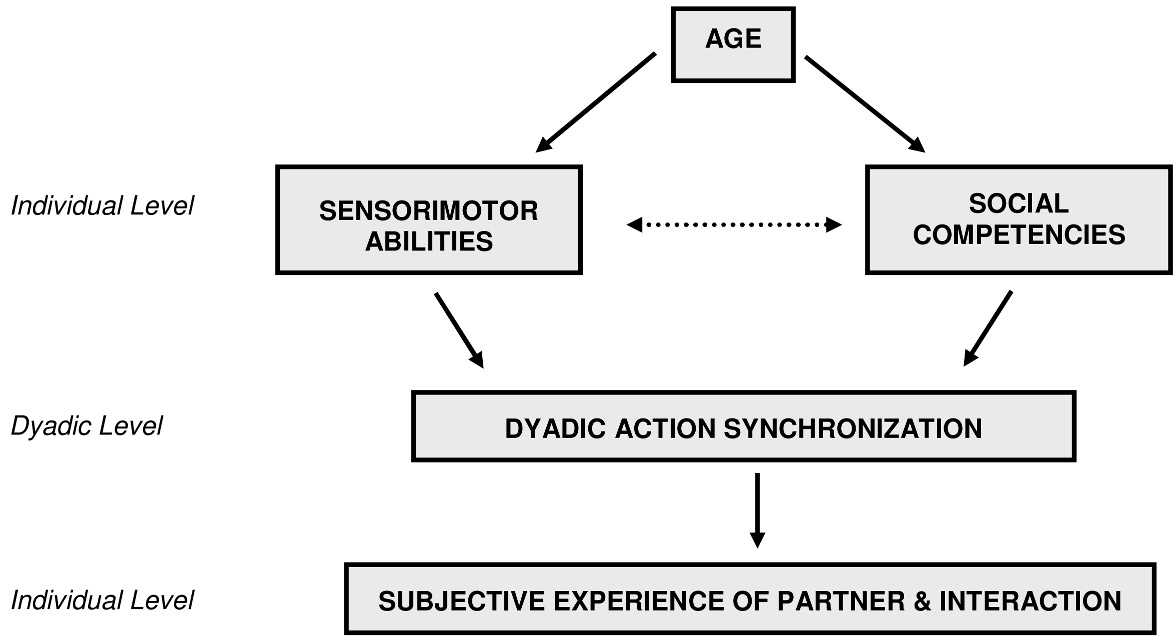

Figure 1.2. The working model: Investigating the development of dyadic action synchronization.

The following sections are ordered in accordance with the three research questions also illustrated in Figure 1.2. Moreover, I will specify the hypotheses that will be tested in the present investigation.

1.5.2 How Do Individual and Age-Related Differences in Sensorimotor Abilities and Social Competencies Relate to Dyadic Action Synchronization?

I propose that dyadic action synchronization is based on two functional components: sensorimotor abilities (i.e., life mechanics) and social competencies (i.e., life pragmatics; see Figure 1.2). Individual as well as age-related differences within the two functional domains are proposed to relate to individuals' ability to synchronize own actions with those of others. In earlier sections, I introduced theoretical assumptions and empirical evidence on developmental change in sensorimotor abilities and social competencies. These aspects can be summarized in the following empirical-based assumption for the present research:

> *Sensorimotor abilities and social competencies relevant for dyadic action coordination improve throughout childhood and adolescence, show a peak in young adulthood, and a decline in older adulthood. Compared to sensorimotor abilities, social competencies show less decline in old age* (e.g., Li et al., 2004; Rasmussen, 1983; Salthouse, 1984; Silbereisen & Ahnert, 2002; Thelen, 1993).

From a developmental perspective, I propose that age-related differences in the individual antecedents of dyadic action synchronization are highly related to the interpersonal outcome because each individual brings his or her own competencies into the interpersonal situation. The first research question therefore focuses on individual and age-related differences in sensorimotor abilities and social competencies as antecedents of dyadic action synchronization.

As will be described in more detail later, sensorimotor abilities were operationalized as individuals' synchronization performance with a metronome. Self- and others' report on social skills and flexibility were used to operationalize social competencies and attitudes. The relationship between age-specific stereotypic expectations and interpersonal action synchronization was explored. The following sections summarize evidence for individual and age-related differences in the indicators of the two functional components.

Individual and Age-Related Differences in Sensorimotor Abilities

In the present study, individuals' ability to synchronize with a mechanical (non-human) stimulus was used as the main sensorimotor predictor of dyadic action synchronization. The assumption was that individuals, who are able to synchronize their actions accurately with a mechanical time keeper, will also show more accuracy when synchronizing with another person. As described above, the most widely used paradigm to assess individuals' ability to synchronize with a mechanical time keeper is the tapping paradigm (for overview, see Aschersleben, 1994). Successful individual action synchronization with a mechanical time keeper is proposed to depend on two essential timing-related abilities: *perception of the temporal properties* of environmental events and *time production* as the execution of self-generated sequences of precisely timed movements (e.g., Drewing et al., 2006; Summers, 2002). Similar, if not identical, mechanisms are assumed to underlie both individual and interpersonal action synchronization: Interpersonal action synchronization requires the ability to perceive others' actions, anticipate them, and react to them (e.g., Knoblich & Sebanz, 2006; Tsai et al., 2006). Individuals who possess timing-related abilities (i.e., time perception and production) can make use of them in individual as well as interpersonal situations and therefore show high synchronization accuracy in both contexts.

Age-related differences. Beyond individual differences in single-person synchronization abilities, results from studies concerning the development of individual synchronization abilities indicate that age-related differences exist as well. A small number of studies focused on developmental change of individuals' synchronization accuracy. Results suggest that the development of individual synchronization accuracy and efficacy follows an inverse U-shaped function that resembles the trajectories of cognitive mechanics across the lifespan (e.g., Drewing, et al., 2006). Tempo discrimination, tempo adaptation, and rhythmic performance are inherent mechanisms already found in neonates and 2- and 4-month-old infants (e.g., Baruch & Drake, 1997; Condon & Sander, 1974a, 1974b; Demany, McKenzie, & Vurpillot, 1977; Pouthas et al., 1996). Further on, by the age of 4–5 years, children can synchronize their clapping to an externally timed tempo (e.g., Drake et al., 2000; Fitzpatrick, Schmidt, & Lockman, 1996). There is also evidence that variability in individuals' synchronized tapping decreases with age during childhood, that is, older children tap more accurately than younger children (e.g., Drake et al., 2000; Smoll, 1974a, 1974b; Volman & Geuze, 2000). Furthermore, some empirical studies reported less accurate synchronization in older adults than in younger adults (e.g., Drewing et al., 2006; Krampe, Engbert, & Kliegl, 2001, 2002; Pouthas, Vanneste, Jacquet, & Gerard, 1998).

It has also been shown that bimanual tapping becomes faster and more accurate (less variable) with age in children. Presumably, this is related to maturation processes of the corpus callosum (e.g., Njiokiktjien et al., 1997; Wolff, Kotwica, & Obregon, 1998), apart from more general refinement in attentional systems (e.g., Diamond, 2000; Jones & Boltz, 1989; Temprado & Laurent, 2004). On average, most of these developmental changes occur earlier for girls than for boys, resulting in gender-related differences among children between 6 and 12 years of age. During this period, girls are more accurate in synchronization, but these developmental sex differences disappear with increasing age (e.g., Hiscock, Kinsbourne, Samuels, & Krause, 1985; Wolff & Hurwitz, 1976).

As discussed above, the interest of this study was in free dyadic synchronization without external time keepers. It is assumed that in natural interactions, individuals' internal clocks function as each others' time keepers and that an adjustment process between the two interaction partners underlies synchronization accuracy. In order to better understand how interpersonal synchronization emerges, it is also important to take into account individual differences in internal time keepers (e.g., variability in preferred tempo tasks). Fraisse and Oléron (1954) reported that individuals show specific tempi (between 400 ms/2.5 Hz and 800 ms/1.25 Hz) in free motor tasks, which are related to chronological age. As early as the age of 2.5 years, individuals have a preferred tempo, which is relatively stable over shorter periods of time (e.g., Drake et al., 2000; Provasi & Bobin-Bègue, 2003; Vanneste et al., 2001). Later studies on preferred tempo underline its lifespan development. They reported clear increases in the intertap interval across the lifespan, that is, a slowing down of inter-response rates. Children, in comparison to adults, showed a preferred tempo that was 400 ms faster (e.g., Jacquet, Gérard, & Pouthas, 1994, cf. Provasi & Bobin-Bègue, 2003; Vanneste et al., 2001). This seems to be related to general slowing of perception and action with advancing age (see also Jagaczinsky et al., 1993; Salthouse, 1985). Interestingly, during childhood, a decrease in speed was also associated with an increase in the variability of the tapping rates (Drake et al., 2000). However, some empirical evidence hints that in older adulthood the precision of the internal time keepers does not generally decrease (Drewing et al., 2006; Pouthas et al., 1998). Still, compared to younger adults, older adults show more deficits in their synchronization abilities when it comes to more complex rhythmic tasks (Jagacinski et al., 1993; Krampe et al., 2001). I assume that interpersonal action synchronization is more complex than individual synchronization with a metronome, for example, because individuals perform in a less stable manner than mechanical time keepers.

In summary, there is empirical evidence for individual and developmental differences in timing abilities, particularly in the ability to synchronize with a mechanical time keeper. In the present study, individuals' general synchronization abilities (based on perceptual and motor skills) are proposed as one of the main sensorimotor predictor of the ability to synchronize own actions with others': Individuals who are able to synchronize with a mechanical time keeper are hypothesized to show higher accuracy in dyadic action synchronization. Because the main focus of the present study was on developmental aspects of interpersonal action synchronization, it is important to stress the empirical findings that synchronization abilities improve during childhood and appear to be relatively well preserved in old age (e.g., Drewing et al., 2006; Vanneste et al., 2001), although deficits relative to younger adults emerge with more complex rhythmic tasks (Jagacinski et al., 1993; Krampe et al., 2001). The effect of individual and age-related differences in sensorimotor abilities on dyadic action synchronization was expected as follows:

Hypothesis 1a: Higher individual sensorimotor abilities within a dyad predict higher accuracy of dyadic action synchronization.

Individual and Age-Related Differences in Social Competencies

Besides sensorimotor abilities, experience-based and socially formed competencies and attitudes are hypothesized to be relevant for interpersonal synchronization (e.g., Tsai et al., 2006). In this study, social skills (i.e., the competence, assertion, and self-control when interacting with others) and flexibility (i.e., the ability to adjust to different individuals across different situations) were used to operationalize social competencies. Social competencies as indicators of life pragmatics were found to develop in early childhood and remain relatively stable until older adulthood (for an overview, see Silbereisen & Ahnert, 2002; Petermann et al., 2004). As an expression of life mechanics, very basic social skills, such as the ability to distinguish between own and others' actions, develop successively in the very first years of life (e.g., Harter, 1998; Rasmussen, 1983). With respect to the age groups of interest to the present study, I therefore assume that all participants had already developed basic social skills before the age of five years (i.e., before participating in the study). Moreover, there are aspects of social competencies that are based on knowledge accumulated from social interactions and thus can be referred to life pragmatics (e.g., Staudinger & Pasupathi, 2000). During childhood, individuals also develop a theory of mind, that is, the ability to interpret others' actions with regard to underlying mental states (e.g., Astington et al., 1988; Baron-Cohen, 1995). However, there is not much evidence for age-related changes in social competencies until very old adulthood (e.g., Happé et al., 1998; Slessor et al. 2007). The main theoretical assumption is that after social competencies have developed during childhood and adolescence they remain relatively stable until old age. I propose that the ability to synchronize one's actions with those of others increases along with the development of social competencies, which are assumed to facilitate the prediction of more realistic consequences of social interaction processes (e.g., Flavell et al., 1993; Yeates & Selman, 1989; see also Section 1.3.2). The ability to predict interaction consequences and react appropriately enables individuals to adjust to different interaction partners in various situations (i.e., interpersonal flexibility). In conclusion, higher levels of social skills and flexibility are predicted to enhance the ability to synchronize with others:

Hypothesis 1b: *Higher individual social competencies within a dyad predict higher accuracy of dyadic action synchronization.*

Excursus: Exploration of Age-Specific Stereotypes

This study also aimed at exploring age-specific stereotypic expectations as an additional pragmatic antecedent to interpersonal action synchronization. In general, stereotypes are thought of as results of top-down processes and not a "data-based" bottom-up impression shaping of the other person. Negative stereotypic expectations towards an interaction partner are found to influence interaction processes (e.g., Bargh, et al., 1996; Filipp & Mayer, 1999). Particularly in the context of interaction processes between individuals of different ages, age-related stereotypic expectations and attitudes may come into play. As can be found in intergenerational exchange processes, younger adults often adjust to older adults, according to the stereotypic expectations they hold with respect to the older age group, for example, the general assumption that older adults become slower and frail (e.g., Brubaker & Powers, 1976; Coupland et al., 1988; Hummert, 1990; Peters, 1971). In general, I assume that expectations that match the true competencies of the synchronization partner may enhance the synchronization process, whereas improper stereotypic expectations more likely complicate synchronization accuracy. However, it was not possible to test this hypothesis in the present study because it was not examined (a) whether participants' age-specific stereotypes matched the actual behavior of the specific interaction partner and (b) whether the interaction partners acted in line with their own age-specific expectations. That is why the influence of positive or negative stereotypic attributions to the age group of the respective partner was explored by examining individuals' age-specific stereotypic expectations as predictors of interpersonal action synchronization accuracy:

Age-specific stereotypic expectations were explored as predictors of dyadic action synchronization accuracy.

To summarize, I hypothesized different facets of sensorimotor abilities and social competencies to be related to the development of dyadic action synchronization. More specifically, developmental differences in the individual predictors account for potential differences in the ability to synchronize own actions with another person. When investigating dyads as research units, the combination of individuals that presumably differ in their individual competencies due to their developmental status is of great interest. The investigation of different age-group compositions of dyads can therefore provide deeper insight into the development of the respective underlying mechanisms. I will introduce respective hypotheses in the following section.

1.5.3 Do Dyads of Varying Age Compositions Differ in Dyadic Action Synchronization?

The second research question refers to age-related differences within dyads of specific age-group compositions that may affect dyadic action synchronization. As reviewed in the last sections, there is empirical evidence for age-related differences in individuals' abilities proposed to be relevant for the development of interpersonal action synchronization. Consequently, I expect developmental differences in the ability to synchronize own actions with others' to become evident between individuals of same- and mixed ages. Hence, to address differences between dyadic age-group compositions, individuals of different ages were paired to form same-age and mixed-age dyads in the present investigation. Due to age-specific individual abilities, differences in interpersonal action synchronization accuracy between different age compositions of the dyads are expected:

Hypothesis 2: *Due to age-related differences in sensorimotor abilities and social competencies, dyadic action synchronization accuracy varies depending on the age composition of the dyads.*

Three sub-hypotheses further explicate these assumed differences between dyads. First, as younger adults are expected to show the highest functioning in both sensorimotor abilities and social competencies, dyads composed of two younger adults are hypothesized to perform most accurately:

Hypothesis 2a: *Same-age dyads of younger adults show the highest dyadic action synchronization accuracy.*

Second, mixed-age dyads are expected to show a different pattern of synchronization accuracy. Due to age-related differences in sensorimotor abilities as well as social competencies, there are differences in the dyadic adjustment processes. Again, as younger adults are reported to show the highest functioning in underlying competencies, they are hypothesized to be able to adjust best in their synchronization performance to all possible partners. For example, younger adults' synchronization behavior can especially be facilitating for children's synchronization performance. That is why the expected synchronization accuracy of dyads with one younger adult is specified as follows:

Hypothesis 2b: *Age-mixed dyads with one younger adult show higher dyadic action synchronization than all other dyads (except same-age dyads of younger adults).*

Broadly guided by the finding of greater interindividual differences in childhood and older adulthood (e.g., P. B. Baltes, Reese, & Lipsitt, 1980; Schaie, 1994), the investigation of more extreme age-group compositions will be more exploratory in nature. Despite an age-related decrease in sensorimotor abilities, relative stability in pragmatics may balance out this loss in old age (e.g., P. B. Baltes & Baltes, 1990). Even though older individuals have difficulties in perceiving others' actions and become slower in their reaction speed, they can compensate by making use of their experience-based knowledge. For example, if they are able to infer a potential (re)action of their interaction partner more accurately than individuals of other ages, this should enhance the likelihood of choosing the appropriate action in time. This suggests that life pragmatics may influence older adults' ability to synchronize their actions with others more than younger adults'.

As comprehensively described in the last sections and illustrated in the working model (see Figure 1.2), I propose that differences between age compositions of dyads are not age effects per se, but rather based on age-related differences in underlying mechanisms (i.e., individual sensorimotor abilities and social competencies). Therefore, the third sub-hypothesis related to differences between dyadic age compositions represents the assumption that the effect of age composition on interpersonal action synchronization is mediated by age-related differences in sensorimotor abilities and social competencies (see Figure 1.3):

Hypothesis 2c: *Differences between age compositions of the dyads can be predicted, in part, by the extent of individual sensorimotor abilities and social competencies.*

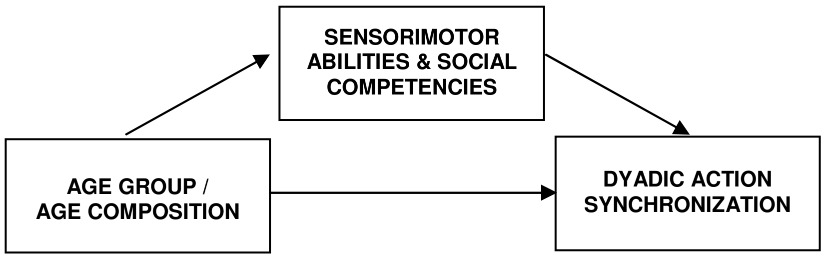

Figure 1.3. The mediator model of the relationship between age-group composition of the dyads and differences in individual antecedents of dyadic action synchronization.

1.5.4 How Does the Accuracy of Dyadic Action Synchronization Affect Individuals' Subjective Experience of the Interaction Partner and the Situation?

The third research question relates to the assumption that differences in dyadic performance affect individual experience. Previous research on interaction processes provided empirical evidence that more accurate or fluent coordination leads to a more positive experience of the interaction and the interaction partner (e.g., Kulesza & Nowak, 2003; Tickle-Degnen & Rosenthal, 1987; van Baaren et al., 2003; Warner, 1992). Interpersonal action synchronization can therefore be understood as a factor that influences interpersonal perception with respect to self- and other-attributions. It is hypothesized that individuals evaluate their partners and the social situation more positively when they are able to adjust their own actions to each other (i.e., show higher synchronization accuracy).

Hypothesis 3: *Individuals in dyads who reach higher dyadic action synchronization accuracy experience their interaction partner and the situation more positively.*

For a summary of the three research questions and associated hypotheses underlying the present dissertation see Table 1.2.

Table 1.2
Summary of Research Questions and Hypotheses

I. How do individual and age-related differences in sensorimotor abilities and social competencies relate to dyadic action synchronization?

1a. Higher individual sensorimotor abilities within a dyad predict higher accuracy of dyadic action synchronization.

1b. Higher individual social competencies within a dyad predict higher accuracy of dyadic action synchronization.

II. Do dyads of varying age compositions differ in dyadic action synchronization?

2. Due to age-related differences in sensorimotor abilities and social competencies, dyadic action synchronization accuracy varies depending on the age composition of the dyad:

2a. Same-age dyads of younger adults show the highest dyadic action synchronization accuracy.

2b. Age-mixed dyads with one younger adult show higher dyadic action synchronization than all other dyads (except same-age dyads of younger adults).

2c. Differences between age compositions of the dyads can be predicted, in part, by the extent of individual sensorimotor abilities and social competencies.

III. How does the accuracy of dyadic action synchronization affect individuals' subjective experience of the interaction partner and the situation?

3. Individuals in dyads who reach higher dyadic action synchronization accuracy experience their interaction partner and the situation more positively.