The role of goal representations

in action control

Der Fakultät für Biowissenschaften, Pharmazie und Psychologie

der Universität Leipzig

eingereichte

DISSERTATION

zur Erlangung des akademischen Grades

doctor rerum naturalium

Dr. rer. nat.

vorgelegt von

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geboren am 10. August 1980 in München

Leipzig, den 21.05.2013

Dekanin

Prof. Dr. Andrea Robitzki

Danksagung

Mein Dank gilt an allererster Stelle meiner Betreuerin Martina Rieger, die immer für mich da war – auch wenn sie nicht in Leipzig war. Ich danke Dir für Deine Geduld und Deine Bereitschaft mit mir alle Fragen – große oder kleine – zu diskutieren und von allen Seiten zu betrachten. Du hast mich durch Deine enthusiastische und unterstützende Art dazu ermuntert, wie eine experimentelle Psychologin zu denken und Probleme anzugehen. Ich werde diese Fähigkeiten auch in Zukunft weiter einsetzen.

Bedanken möchte ich mich auch bei Wolfgang Prinz, der für eine offene und kollegiale Forschungsumgebung sorgte und Raum schuf für anregende und unterstützende Diskussionen innerhalb der Arbeitsgruppe.

Auch meinen Kollegen und Mitdoktoranden bin ich dankbar für die gemeinsame Zeit, die Diskussionen und die Hilfsbereitschaft. Ich möchte mich auch herzlich bei Henrik Grunert, der mich bei technischen Fragen tatkräftig unterstütze und bei Gudrun Henze für die zuverlässige Organisation im Hintergrund bedanken. Ein besonderer Dank gebührt auch meinen fleißigen und zuverlässigen Hilfskräften Anne Wagner, Franziska Riedel und Therese Himmel. Ihr seid die Besten.

Danke sage ich auch meiner Familie, meinen alten und neuen Freunden und meinen lieben Schwestern, die immer für mich da waren. Ein besonderer Dank gilt meiner Mama und meinem Papa, die immer ein großes Vorbild für mich waren und die mich zu einem weltoffenen und wissbegierigen Menschen gemacht haben.

Ganz besonders danken möchte ich meinem Mann für seine immerwährende Unterstützung, Aufmerksamkeit und Motivierung. Du bist *mea fortuna*. Gemeinsam mit unserem wundervollen Sohn erinnert ihr mich daran, was wirklich wichtig im Leben ist. Danke für eure Liebe. Ich freue mich auf die nächsten Schritte auf unserem gemeinsamen Weg.

Contents

Chapter 1

1. Introduction

"Never confuse movement with action."

Ernest Hemingway

This quotation originates from a conversation the famous author Ernest Hemmingway once had with Marlene Dietrich. The actress had received a lucrative job offer at a Miami night club, but was debating whether or not she should accept it. Hemingway advised: "Don't do what you sincerely don't want to do. Never confuse movement with action." (Hotchner, 1966).

This short advice shows two major aspects when it comes to the field of movements and actions: first they can be confused, although they are clearly not the same and it is not wise to confuse them. Second, what differentiates an action from a movement is that an action is conducted to achieve a certain goal. To interact in a meaningful way with our environment we perform goal-directed actions. There are as many different possible action goals as there are people and circumstances in which they are acting. However, some broad categories in goal-directed actions can be detected that play a fundamental role in our everyday life. One of those categories is whether we aim towards a change in the environment or towards a change of our own situation in the environment. If we want to change our environment we want to produce a certain effect –whereas if we want to change our own situation in the environment we want to move towards a physical target. An effect in the environment would be for example if -after pressing the light switch- the light goes on. It can also be the goal of an action to move towards a physical target. An athlete during a basketball game is an example here. She hast to run to a certain location to catch the ball. Moreover, she has to reach that location at exactly that point in time when the pass of her teammate arrives. As in this example it is happens often that we want to be at a certain position in space and/or at a certain point in time.

When we think or talk about our actions and their underlying goals what might usually come into our minds are more complex actions and higher order action goals. Such complex goals are mostly not achieved by one or a few single actions but due to a highly complex series of actions that can even span over a long time period - like going to university in order to get a masters degree. Simple actions and goals of little complexity as the examples described above come to the mind less often. We do not have to think about such seemingly trivial actions like reaching out in order to grasp a cup of coffee or pressing a key of our computer keyboard in order to write a text. However, if we have to perform such a simple action for the first time or under unfamiliar circumstances it becomes obvious that they are not trivial at all. If one tries for example to brush her teeth with the non-dominant hand or use a computer keyboard designed for Chinese letters (and not being Chinese) it will be the case that one has to focus all of her cognitive resources on performing that simple action.

A lot of research has been conducted in order to evaluate how such simple actions are performed. However, there is a lack of research comparing specifically which roles different kind of action goals play for action control. This dissertation aims at investigating the question how such simple, intentional actions are controlled and what role different action goals play for their control. More specifically the aim was to determine how internal goal representations influence action execution. This was realized with a series of studies investigating *how* participants perform simple, well-defined actions.

Before describing the research questions in more detail, this introduction will first give a brief overview of basic concepts and empirical findings concerning action control and show which topics in this broad research field are covered by this dissertation – and which are not. Second, the ideomotor theory of action control and empirical findings related to it will be presented as a theoretical framework underlying the here presented studies. Based on that framework, an outline of the three studies, their main research questions and a brief summary of the main results will follow. Limitations and possible future research questions will be highlighted in the last section of the first chapter.

1.1. Action control: Basics

First, I will provide a simple model for the basic process of action control to pinpoint the research questions in the broad field of action research, and then describe important empirical findings concerning the physical appearance of movements (that is their kinematics), before I will finally introduce two different explanatory approaches for those empirical findings.

It is not easy to exactly define what an intentional action is. Even though everybody has a clear intuitive understanding what is meant by acting intentionally, an accepted, clear definition still does not exist. One approach to provide a working definition for intentional actions is to contrast them with reflexive or stimulus-driven actions (that is externally generated actions). In subjective experience there is a clear qualitative and phenomenological difference between both types of motor activity (Obhi, 2012). On an empirical level there is indeed evidence both may be processed in different ways by the motor system (e.g. Mueller Brass, Waszak, & Prinz, 2007; Waszak, et al, 2005; Obhi & Haggard, 2004). Two basic features are postulated by most scientific definitions of intentional actions: they are purposive and endogenous (Brass & Haggard, 2008; Haggard, 2008, Jahanshahi & Frith, 1998). That is, intentional actions are movements that are directed towards an action goal (purposive). Moreover, they are conducted because of the agent´s own choice to perform the action in question instead of an external cause (endogenous). In this dissertation intentional actions will be defined as movements that are performed as means for certain ends or goal-directed movements. In the following I will use the term action when a goal-directed movement is meant, whereas I will use the term movement whenever the focus is laid on how a movement is actually physical carried out. A simple model provides three steps in action control, where action execution is seen as the last step.

1.1.1. Three steps in action control

When it comes to investigating actions and their underlying mechanisms of control in the field of experimental cognitive psychology usually a small time window of preparing and executing intentional actions is considered. Similarly, this dissertation does not deal with motivational or voliational aspects of actions but with the actual execution of the action in question. In an experimental context intentions are implemented by instructing participants what to do during the experiments and it is assumed that they intend to act as instructed.

It is common to differentiate three stages of action control: action selection, action initiation, and action execution. Action selection is the earliest stage in the action production process and refers to the selection of different possible motor responses from a set of predefined responses (the so called response set). The response set contains a fixed number of response alternatives. The higher the number of alternative responses is, the longer it takes to select an appropriate response ("Hick`s Law", Hick, 1952). After an action has been selected it has to be initiated. Finally, the action in question has to be physically carried out which is referred to as action execution (cf Rosenbaum, 1980). Action selection and initiation can be subsumed as action preparation and precede the overt action execution phase. In traditional stage theories it is assumed that those three stages are independent of each other and have to be processed sequentially (e.g. Spijkers & Walter, 1985; Sanders, 1980; Sternberg, 1969). Each stage has to be controlled independently and has different variables that can pose a possible influence. For example, stage theories assume that stimulus-response compatibility effects can only be effective in the action selection stage (cf Hommel, 1997). In contrast, other explanatory approaches of action control like the ideomotor theory (which will be discussed in more detail later in this chapter) do not assume that theses stages are strictly independent and have to be processed sequentially. Nevertheless, the just described subdivision of the action control process in three different stages is intuitive and can be maintained for pragmatic reasons without claiming to stick to theoretical implications of traditional stage theories. The here presented studies investigated action *execution.* The stage of overt action execution starts whenever a movement is observed and is thus clearly separated from the action preparation phase.

For this aim movement kinematics were analyzed. Movement kinematics reflect properties of space (where) and time (when) of a movement in question. A wide variety of different kinematic variables is analyzed in cognitive psychology and in related fields like for example in human computer interaction. It is common to analyze movement time, velocity and acceleration profiles, or variables capturing temporal and spatial accuracy.

1.1.2. Empirical findings on the physical appearance of movements

Action execution has been studied experimentally for over a century. Often simple actions directed towards physical targets are studied as it is assumed that the understanding of such simple actions forms the basis for understanding more complex actions. In the following I will briefly describe major findings concerning kinematics of actions aiming towards spatial and temporal targets that are relevant for the here presented studies.

Among the pioneering works that influence research until today are the works of Woodworth (1899) and Fitts (1954) describing human aiming movements towards spatial targets. Woodworth (1899) described the limitation of the motor system to be fast and accurate at the same time. Using mean movement velocities as independent variable (defined by a metronome) he measured spatial error rates of repetitive aiming movements between two spatial targets at fixed distances. With visual feedback available error rates increase as velocities increase. This relation of movement speed and spatial accuracy is known as the speed-accuracy tradeoff.

Using the same type of repetitive aiming movements Fitts (1954) varied movement distances and target width and measured movement times when participants were instructed to move as fast and as accurately as possible (an instruction that has been frequently repeated in numerous experiments in psychological research until today; a version of this classical task using discrete movements was conducted by Fitts & Peterson, 1964). He found that movement time increases linearly with task difficulty. Fitts specified task difficulty (index of difficulty: ID) as a function of target width and target distance. This relation has found such broad empirical evidence that it is widely known as Fitts´ Law (Keele, 1968) and thus became one of the few accepted laws in psychology (for reviews and mathematical variants of Fitts´ Law see Plamondon & Alimi, 1997, Beamish, Bhatti, Mackenzie, & Wu, 2006). Fitts´ Law has been found to hold in a variety of tasks under a variety of circumstances including for example moving around obstacles (Jax, Rosenbaum, & Vaughan, 2007), tasks performed by dyads (Mottet, Guiard, Ferrand, & Bootsma, 2001), or performing translational as well as rotational movements (Stoelen & Akin, 2010). It holds for real, as well as imagined movements (Wilson, Maruff, Ives, & Curri, 2001; Choudhry, Carmann, Bird, & Blakemore, 2007; Macagua, Papailiou, & Frey, 2012). Further, it can also be applied when aiming with a variety of computer devices (Kopper, Bowman, Silva & McMahan, 2010). The importance of spatial targets for action control is not only demonstrated by these findings regarding movement times and spatial accuracy, but is also reflected by velocity and acceleration profiles of actions aimed at spatial targets. Many studies demonstrated that such actions frequently show an asymmetric velocity profile: the skewness in velocity profiles increases as spatial accuracy demands of a task increase and/or targets are small (Elliott & Hansen, 2010; Rieger, 2007a; Elliott, Helsen, & Chua, 2001; Helsen, Elliott, Starkes, & Ricker, 1998; Hogan & Flash, 1987; MacKenzie, Marteniuk, Dugas, Liske, & Eickmeier, 1987).

But not only spatial targets have been shown to play an important role for action control. The same holds true for temporal targets. Actions towards temporal targets have been studied frequently, often in the context of sensorimotor synchronization (for an overview see Repp, 2005). When participants perform tasks requiring repetitive synchronization with temporal targets (e.g. the beat of a metronome) it is observed that movement times are more variable the higher the interval between two successive temporal targets is (e.g. Wing & Kristofferson, 1973). When comparing movement kinematics of actions towards a temporal target with those away from it asymmetric velocity profiles (Rieger, 2007a) and movement times (Balasubramaniam, Wing, & Daffertshofer, 2004; Torre & Balasubramaniam, 2009) are observed. In the so called "event structure account" temporal targets are viewed as events structuring an action or a sequence of actions. The relative importance of events within this structure depends on the relative salience of the different events (Ivry, Spencer, Hazeltine, & Semjen, 2004): salient events are assumed to be higher hierarchical goals. At such events higher in the hierarchy there is a pronounced asymmetric velocity profile and temporal variability is lower (e.g. Kelso, Buchanan & Wallace, 1991; Byblow, Carson, & Goodman, 1994).

The just described results that were obtained in the broad field of research engaged in the study of actions control are by no means complete. Instead, they were selected on the one hand to highlight major findings of studies analyzing movement kinematics that will be relevant for the studies of this dissertation and on the other hand to demonstrate the importance of external spatial and temporal targets for action control. The previous paragraphs have not offered explanations why movement kinematics show their typical characteristics under specific circumstances, such as asymmetric velocity profiles. Traditional explanations assume that in movements aimed towards physical targets the typical kinematics reflect physical properties of those targets (e.g. position and time). According to this point of view humans react to stimuli in their external world by using certain movement kinematics. The above mentioned stage theories of action control for example follow this line of argumentation.

1.1.3. Bottom-up and top-down action control

In general, one can distinguish between two different approaches in the explanation of action control: bottom-up control and top-down control. The notion of bottom-up control means that explanations of action control can be derived by the current situation a person finds herself in. For example a person sees an object she wants to have and grasps it, or feels too hot in the sun and so changes her position to be at a shadier place. In a more theoretical language the following happens: a person perceives something (the object, the hotness) and forms a representation of the perceived object that is internally processed. Such representations are evaluated and a suitable action is then chosen and conducted in order to change the environment or the persons´ position in it. So the processing pathway leads from the bottom – that is from perception – up to the inner control system that in turn generates an answer based on that processed informational input. As already mentioned, in such explanatory approaches movement kinematics are explained by a specific set of perceivable, physical circumstances that are given in the current situation.

In contrast, in the here presented studies I will argue that a person does not only react to such perceivable circumstances by using specific movement kinematics, but instead that such specific movement kinematics are also influenced by the specific goals a person wants to achieve. In this point of view movement kinematics reflect the *why* and *what for* of an action, instead of the *where* and *when* (cf Prinz, 2012). Thus, I will argue that top-down control also has to be taken into account in order to explain specific movement kinematics. Top-down approaches assume that the processing pathway leads from the top – that is from a persons´ represented goals – down to the planning and generation of suitable actions to achieve the goals. Such goals refer to circumstances that are not given in the current situation a person finds herself in, but that are desired or intended. I thereby assume that it can be the goal of an action to change the environment, but also to change one´s position in the environment. However, this does not mean that bottom up control does not exist or that both types of action control are mutual exclusive. On the contrary, one has to bear in mind that it is rarely the case that human movements can be divided in such that are only guided by an agent´s intention and such that are only determined by external stimuli configurations. It rather seems to be fruitful to think about a continuum with internally and externally generated movements on its very extremes (Krieghoff, 2009).

A theory that provides mechanisms and explanations of how exactly such a top down control is possible is the ideomotor theory of action control (James, 1890/1981; Prinz, 1997). In the following I will describe the ideomotor theory in more detail, provide empirical evidence supporting it, and will then elaborate some gaps in the empirical evidence that this dissertations tries to fill.

1.2. *Ideomotor theory of action control*

Ideomotor theory of action control dates back to the 19th century (e.g. Herbart, 1816; 1825; Laycock, 1845; Carpenter, 1852; Lotze, 1852; Harless, 1861, for a historical overview see Stock & Stock, 2004). The main idea is that (mental representations of) actions and (mental representations of) their consequences are tightly linked and this connection can be used to realize intentions by performing an action. It was especially established in scientific psychology by the work of William James (1890/1981). In modern times its ideas were recovered again (Greenwald, 1970; Prinz, 1987) and find widespread resonance in the study of action control until today (e.g. Elsner & Hommel, 2001; Hommel, Alonso, & Fuentes, 2003; Kunde, Koch, & Hoffmann, 2004; Ziessler, Nattkemper, & Vogt, 2012; for recent reviews see Nattkemper, Ziessler, & Frensch, 2010; Shin, Proctor, & Capaldi, 2010). The ideomotor theory covers two main features. First, it states that a person can form associations between executed movements and their perceivable consequences ("learning principle", Prinz, 2012) and second it states that such associations can be used afterwards to plan and execute a desired action by anticipating the intended perceptual consequences ("performance principle"; Prinz, 1997, 2012).

1.2.1. Learning principle

The first step that needs to be fulfilled in order that intentions can be effective for action control is that associations between movements and their perceivable sensory consequences have to be formed. Whenever a movement is performed it is followed by specific sensory consequences (action effects in the following). These effects can either be related to the body of a person like the kinesthetic sensation when pressing a button, or also a specific body posture when performing yoga. These kinds of effects are called "resident" effects. In contrast they can also be related to the external world like the visual sensation when the light goes on after a switch has been used, or the auditory sensation of a tone after a piano key has been pressed. These kinds of effects are called "remote" effects (the notion of remote and resident effects was introduced by James, 1890/1981). It is assumed that whenever such remote or resident effects occur contingently (that is reliable with the same effect) after a movement has been executed, effect representations and motor representations become associated, that is, closely linked and stored together.

There is a huge body of literature showing that action – effect associations in the sense of ideomotor learning are actually formed as just described (e.g. Elsner & Hommel, 2001, 2004; Hommel, Alonso, & Fuentes, 2003). A classical study that assessed the formation of action-effect associations was conducted by Elsner & Hommel (2001). In a two step paradigm participants performed two key-presses (left or right) whenever there was a go-signal in a first (training) phase. They could choose freely which key to press. Each key-press was followed contingently by a specific tone (e.g. left hand key-press by a high pitch tone, right hand key-press by a low pitch tone). Importantly, participants were not required to pay any attention to those tones but they were asked to distribute their key-presses approximately equally often between the left and right hand. In a second (experimental) phase participants again were asked to respond to a go-signal with free-choice key-presses. They should try to distribute their key-presses approximately equally often between left-hand and right-hand key-presses. In this phase however the tones (which can be viewed as effects of the key-press in the first phase) were presented together with the go-signal and therefore now served as imperative stimuli for the free-choice reactions. Results showed that reaction times were faster for responses compatible to those in the acquisition phase (e.g. a left hand key-press was produced faster after a high pitch tone). The interpretation of this finding is that action-effect associations have been formed in the training phase. Similar effects of faster responses (Hommel, Alsonso, & Fuentes, 2003; Rieger, 2004; Kray, Eenshuistra. Kerstner, Weidema, & Hommel, 2006; Hoffmann, Lenhard, Sebald, & Pfister, 2009) to acquisition-compatible action-effect mappings and a higher probability to produce acquisition-compatible responses (Pfister, Kiesel, & Hoffmann, 2011) have been frequently found. Many other versions of such a paradigm consisting of a training phase in which action-effect associations are formed as a by-product and an experimental phase in which the existence of such associations is tested, exist. For example, in a forced-choice reaction task faster reactions for acquisition-compatible responses were reported if the effects in the acquisition phase consisted of letters instead of tones and they were presented together in the test phase with the imperative stimuli adapting a flanker task (Ziessler, Nattkemper, & Frensch, 2004; Ziessler & Nattkemper, 2002; Eriksen & Eriksen, 1974). The formation of long-term associations between actions and their effects has also been demonstrated in studies on infants (Eenshuistra, Weidema, & Hommel, 2004; Karbrach, Krey, & Hommel, 2011; Verschoor, Weidema, Biro, & Hommel, 2010) and animals (de Wit, Niry, Wariyar, Aitken, & Dickinson, 2007; Rescorla, 1995; Randolph, 1986).

The theoretical foundation for action-effect learning is laid by the claim of a common representational domain for perception and action. The principles of such a common representational domain have been elaborated in the theory of event coding (TEC, for overviews see Hommel, Müsseler, Aschersleben, & Prinz, 2001; Prinz, 2002; Prinz, Aschersleben, & Koch, 2009). It is assumed that information from the motor and the sensory domain form representational codes, both referring to external events (to perceived or anticipated consequences of acting, or to perceived or anticipated sensory events, respectively). The codes entail a bundle of different features, like location and target object or color and salience. These codes (normally called action codes on the motor side and event codes on the sensory side) are stored in a common representational domain and are therefore commensurable or translatable from one form to the other in a direct manner. The common representational domain for action and event codes also leads to the activation of the associated action codes whenever the contingent action effect is perceived not as action effect but as a stimulus. This is what happens in the just described studies showing a priming effect of an imperative stimulus that has been an action effect in the preceding training phase. The facilitation of the compatible actions can be explained by their co-activation when the former action effect is perceived as stimulus.

Learning of action-effect associations is the first step necessary for explaining how intentional actions can be carried out according to the ideomotor theory. A second step that explains how these associations can be used to plan and execute desired actions is now described and empirical evidence on this topic is summarized.

1.2.2. Performance principle

The core idea of an ideomotor explanation of action control is that an action is planned and executed by the anticipation of its intended perceptual consequences (Prinz, 1997). Action-effect associations acquired in the past can be useful for action control in two distinct ways. One way is that they allow a person to anticipate the outcome of an action. The actual outcome of an action can be compared with the expected outcome. This evaluative function (Kunde, et al, 2004) can be used to correct errors and adapt actions in order to act more precisely. More importantly (and in contrast to bottom-up approaches of action control) ideomotor approaches additionally postulate that an action is planned and executed by the anticipation of the intended perceptual consequences. This generative function (Kunde, et al, 2004) is the key concept for action control according to the ideomotor theory and therefore a top-down approach. Put in other words the close connection between an action and its contingent perceivable effect can be used to evoke the appropriate motor code by the anticipation of the desired event code. This is possible as both the action and the event code are represented in a common domain, as described above.

Empirical evidence for the performance principle of the ideomotor theory has been obtained in a variety of studies (e.g. Knuf, Aschersleben, & Prinz, 2001; Kunde, 2001, 2003; Kiesel & Hoffmann, 2004; Rieger, 2007b). TEC postulates that it rather applies to late cognitive products of perception and early cognitive antecedents of action (that is action planning or action selection and initiation). Consequently, most of the studies (but not all) addressing the issue of how an action is controlled in the view of ideomotor theory have engaged in finding evidence for the influence of anticipated action effects on action planning.

While in the experiments described above action-effect associations between actions and arbitrary action effects are learned in a trainings phase, finding evidence for the influence of anticipated action effects (and therefore upcoming events) on action planning has to use a different approach. An approach that makes it possible to indirectly asses its role is to investigate action control under circumstances where there is a dimensional overlap between features of the action and features of the effect. Such response-effect compatibility paradigms do not need to present the former action effect as a stimulus, but investigate its influence before the movement is actually executed in a more direct way.

This approach was used by Kunde (2001) who showed that participants respond faster if an action produces an effect that is spatially compatible with its response in a forced-choice reaction task. Participants responded to the colour of a stimulus with one of four different key-presses on keys aligned horizontally. As a visual action effect of each response one of four boxes (also aligned horizontally) lit up on a computer screen. Most importantly, there was a compatible condition in which locations of the responses and locations of the effects corresponded, and an incompatible condition, in which locations of the responses and the effects did not correspond. In compatible conditions (e.g. a left hand key press produced the illumination of a box on the left side of the monitor) responses were initiated faster than in incompatible conditions (e.g. the left hand key press produced a lighting of a box on the right side of the monitor). Because both the compatible and the incompatible condition had the same imperative stimuli the result can only be attributed to anticipated action effects being effective *before* the response has been executed. That was the case even though participants were not explicitly instructed to produce an effect. Comparable results have been found in other domains (e.g. Janczyk, Skirde, Weigelt, & Kunde, 2009; Keller & Koch, 2006, 2008). For example, similar results were obtained when using auditory action effects (Kunde, et al, 2004), or typing responses and letters as visual action effects (Rieger, 2007b).

The overlap of features of the action and the anticipated action effect facilitates action planning due to bidirectional co-activation of an action and its corresponding effect. Kunde and colleagues also addressed the question of whether effect anticipations can be shown for action selection and action initiation (Kunde et al, 2004) and therefore tried to disentangle the influence of effect anticipations on early and late phases of action planning. They found evidence that anticipated goal representations influenced both action selection and initiation and suggested that both should not be seen as independent from each other but rather as different phases of a single process in which anticipated goal representations are activated and remain activated until the movement is actually carried out. Using an indirect priming paradigm Ziessler and colleagues (Ziessler et al, 2012) come to a similar conclusion. In summary there is little doubt that anticipated action effects influence action planning due to co-activation of action codes and event codes. What is less clear is if the same is true for action execution.

A reason for the relatively little number of studies engaging in the question of if and how anticipated action effects influence action execution can be seen in the claim made by TEC (Hommel et al, 2001) that TEC rather applies to early cognitive antecedents of action than “late” action (see chapter 1.2.1). However, using a response-effect compatibility paradigm as described above an influence of anticipated action effects was also demonstrated for action execution. Kunde and colleagues (2004) specifically addressed this question. They observed that peak force was influenced by the intensity of the produced auditory effects: peak force was higher when followed by a soft tone than when followed by a loud tone. This was the case independent of the overall response force - that is for soft and forceful responses.

While the authors conclude that there is evidence for the influence of anticipated action effects on action execution they also admitted that alternative explanations can also be found for their results. Moreover, in this study only one variable (peak force) was analyzed as measurement for action execution and the results are limited to the domain of auditory action effects.

Most of the studies described so far in the context of ideomotor theory of action control deal with key-presses or other responses where comparable little measurable movement is conducted at all, while the sophisticated kinematic analyzes of the studies described above (see chapter 1.1.2.) are usually conducted in the field of different theoretical approaches. Thus, up to date the role of anticipated action effects on action execution has been mostly neglected when it comes to analyzing how an action is actually carried out in order to obtain certain goals. Consequently, in their recent review Shin and colleagues (2010) challenge ideomotor theory to take action execution into account, as otherwise it would be difficult to dissociate it from competing theories. In their view the inclusion of explanations of the influence of "images" on action execution is a necessary prerequisite of a "strong" ideomotor theory - that is a version of the theory that is not in need of any translational steps between action and perception. Only such a strong version would preserve its unique status for the depiction of the relation of action and perception. Kunde (2001) and colleagues (2004) also suggested that the influence of anticipated action effects on "late" action should be taken into account in order to provide a full picture of action control.

The just described studies also reveal another topic that attracts more attention than others: usually action effects are considered, for example a tone as an auditory action effect or a light flash as a visual action effect. Coming back to the first paragraphs of this chapter these studies implicitly consider the goal of an action to consist of a change of the environment (i.e. to produce an effect). However, as described above it can also be the goal of an action to change one´s own situation in the environment (i.e. to move to a target). Targets as action goals are usually not considered in studies on ideomotor theory of action control. An exception is a study by Pfister and colleagues (2009). However, in contrast to the here presented studies, in their study effects were always additionally produced at target locations. In a lively debate of whether action-effect learning takes place only in movements that are guided by an agent´s intention (e.g. as in the study by Elsner & Hommel, 2001) or can also be observed in movements that are determined by external stimuli configurations, targets defined as external stimuli play a prominent role (e.g. Herwig & Waszak, 2012). However, in this dissertation the term target is used in a different way. The action usually *follows* the target in stimulus-based actions, and learning of subsequent effects is incidental. In contrast, in actions towards targets as defined here the action is produced in order to coincide with a future event and thus the action of interest *precedes* the target.

Above I have shown that physical targets are highly relevant for action control and action execution (see chapter 1.1.2.). Traditionally, it is assumed that movement kinematics of actions towards targets reflect physical target properties. To contradict this view Rieger (2007a) investigated the role of temporal and spatial targets for action execution. It was found that kinematics of actions directed towards physical targets cannot only be viewed as mere reactions to those targets. Instead, they evoke intentional goals such as "to be at a certain place at a certain point in time". Moreover, such goal representations do not only depend on physical target characteristics but on how such targets are represented. For example, a combined target (consisting of a temporal and spatial target) was represented as major goal in comparison to a single (temporal or spatial) target. Rieger concluded that goal representations influence movement kinematics by the anticipation of the desired goal states and are then chosen in order to suit this goals state most optimally. Therefore, there is some evidence that targets also evoke intentional goals, while there is also the need to elaborate this question further. Taking this as a starting point, I will know describe the research questions in more detail.

1.3. *Research questions*

In this dissertation it is assumed that movement kinematics reflect the internal representation of the action goal. Ideomotor theory of action control is thereby the theoretical approach used to explain how goal representations can influence action execution. However, it was shown that in the ideomotor literature targets are almost neglected as action goals. Moreover the preceding paragraph has given a clear indication that more investigations are needed addressing specifically the role of anticipatory goal representations on action *execution*. I thereby assume that it can be the goal of an action to produce an effect, but also to move towards a physical target. The term target will be used to describe physical characteristics of the environmental situation, while the term goal will be used to reflect a persons' representation of that target combined with the intention to be at the target or to produce the effect.

It was analyzed *how* participants executed continuous-reversal movements (on the medial-lateral axis) on a writing pad. The following variables describing the kinematic curvature were analyzed: a) the time to reach peak velocity relative to the complete duration of the movement (proportional time to peak velocity in %, PTPV), and b) the time spent on one movement relative to the time spent on the complete reversal movement (proportional movement time in %, PMT). Kinematic patterns were compared in order to evaluate the underlying mechanisms of action control. A typical *spatial* kinematics pattern is characterized by relative high PMT and low PTPV, and a typical *temporal* kinematic pattern is characterized by relative low PMT and high PTPV. Both patterns are suited to achieve the intended goal of an action most optimally (Rieger, 2007). Further, temporal and spatial accuracy were analyzed. Specifically, movements towards targets and towards effects were examined and compared in both the temporal and the spatial domain. Furthermore, goal representations were directly manipulated in order to evaluate their influence on action execution. Accordingly, the present work consists of three studies that will be described in the following.

1.3.1. Study 1

The first objective of the present dissertation was to address the question whether action execution follows similar principles in actions that are directed towards auditory-temporal targets and towards auditory-temporal effects. It was hypothesized that movement kinematics in both cases should be very similar because it is assumed that targets and effects are both represented in a similar way as goals of an action. In the case of effects the goal is to produce a change in the environment, whereas in the case of targets it is the goal to be at a certain place at a given time. Such goal representations should shape movement kinematics by the anticipation of upcoming events in a comparable manner. Additionally, it was investigated how certain goal characteristics (i.e. loudness) are integrated into the representation. Slight differences between target-directed and effect-directed actions were also expected due to assumed differences in the precision of temporal information and required information processing demands. For these aims, it was analyzed how continuous-reversal movements as described above were executed and additionally timing mechanisms were analyzed. In three experiments participants either synchronized movement reversals with regularly presented tones (temporal targets), or produced tones their selves at reversals isochronously (temporal effects). Target-directed and effect-directed actions were compared across conditions in different goal sets with varying goal features (Experiment 1), integrated in one condition (Experiment 2), or compared across conditions with additional spatial demands (Experiment 3). The study will be presented in detail in Chapter 2 of this dissertation (Walter & Rieger, 2012a).

1.3.2. Study 2

Having demonstrated that actions conducted towards auditory-temporal targets and effects are controlled in a similar way, the second objective of this dissertation was to investigate whether these findings also apply to spatially restricted movements. Again it was assumed that visual-spatial targets and visual-spatial effects are represented as action goals shaping movement kinematics in a specific manner. Moreover, it was assumed that Fitts´ Law (see chapter 1.1.2.) can be applied to movements towards targets and effects. Differences between targets and effects due to higher cognitive demands of effects were also expected. In two experiments participants either had to reverse their movements within black boxes that were constantly present (spatial targets) or had to produce black boxes at movement reversals (spatial effects). The comparison across conditions in sets with different goal characteristics between target-directed and effect-directed actions was of particular interest in Experiment 1, since it was possible to investigate how goal representations are formed here. To enhance differences between them both were performed within one condition in Experiment 2. The study summarized here will form Chapter 3 of this dissertation (Walter & Rieger, 2012b).

1.3.3. Study 3

Finally, the aim of Study 3 was to investigate further how goal representations influence action execution. A different approach was used here: goal representations were manipulated by the given instructions. The aim was to disentangle the role of goal representations and the role of physical target characteristics. Based on the previous results and the theoretical assumptions detailed above, it was assumed that cognitive representations of action goals shape movement kinematics rather than their physical characteristics. While performing continuous reversal movements visual-spatial targets were always presented, whereas auditory-temporal targets were manipulated by the given instructions. Temporal targets were either acoustically presented (present), participants had to imagine them (imagined), or neither presented nor imagined (absent). Using this approach, goal representations of present and imagined targets should be similar, even though they differ in their physical characteristics. In contrast, goal representations of imagined and absent targets should differ, even though their physical characteristics are the same. Consequently, it was expected that movement kinematics towards present and imagined targets are similar, but are different from kinematics towards absent targets. Gradual differences were also expected due to differences in the precision of the representation of present and imagined targets. The experimental setup of Study 3 was realized with different sets of combined temporal and spatial targets on the one side of the reversal movement and a single temporal or spatial target on the other side. Chapter 4 will present the study outlined above (Walter & Rieger, in preparation).

1.4. Summary of the main results

Before presenting the studies that address theses research questions in detail I will present a brief overview of their main results. The first study (Walter & Rieger, 2012a) dealt with the question whether underlying principles of action execution are similar in target-directed and effect-directed actions in the temporal domain. It was found that movement kinematics of target-directed and effect-directed actions were very similar, indicating that both are controlled in a similar way, including the anticipation of upcoming events. Similar kinematic patterns were observed in a variety of experimental manipulations: an irrelevant goal characteristic (i.e. loudness, Experiment 1) was integrated in the goal representation in both cases. When targets and effects were integrated within the same reversal movement, similarities were enhanced (Experiment 2), and even when the task posed spatial demands in addition to temporal demands (Experiment 3), target- and effect-directed actions were performed in a very similar way. Moreover, similar timing mechanisms of target-directed and effect-directed actions were demonstrated. The second study (Walter & Rieger, 2012b) asked whether comparable results as in the first study can be obtained in the spatial domain. In summary, the results indicated similar control mechanisms for target-directed and effect-directed actions in the spatial domain. It was shown that both have a typical spatial kinematic pattern and that both can be described by linear functions as suggested by Fitts´ Law. Slight differences in the kinematic patterns obtained in both studies were attributed to higher cognitive demands of effects, which are assumed consequently to be represented less precisely than targets. Taken together the results of the two studies could convincingly show that ideomotor theories of action control should incorporate action targets as action goals similar to action effects. Further, they provided evidence for the influence of goal representations on action execution.

The third study (Walter & Rieger, in preparation) aimed at disentangling the role of physical target characteristics and the role of goal representations by directly manipulating goal representations via the given instructions. Results showed that kinematics of movements towards imagined targets resembled those towards present targets, but not absent targets when a temporal target existed on one side of the reversal movement but not the other. This was the case even though physical characteristics of the stimulus situation were the same when participants moved to imagined and absent targets. When a temporal target existed on both sides of the reversals no differences in the kinematic pattern between movements towards present, imagined and absent targets were obtained indicating that participants may automatically form temporal goal representations in continuous reversal movements, even if no targets are present or imagined. Further, it was shown that imagined targets are represented less precise than presented targets. The results indicated that the representation of targets as temporal goals, rather than physical target characteristics shapes movement kinematics in a specific manner. Thus, action control relies on internal goal representations as ideomotor theory suggests. However, the actual presence of targets plays an important role for the precision of action execution.

1.5. Considerations, limitations, and perspectives

The findings of this dissertation suggest that it can be the goal of an action to change one´s environment as well as to change one´s position in the environment. Further, the representation of such intentional goals shapes movement kinematics in a specific manner by the anticipation of an upcoming event. Ideomotor theories of action control can also be extended to the late phase of action execution. While the obtained results constitute new and exciting data, they only represent the first steps towards a better understanding of the influence of goal representations in action control.

A few considerations can be made concerning the methodological approach used in the here presented studies. In order to obtain control to a high degree over possible influences on action execution simple actions in a highly standardized setting were analyzed. While this procedure secures good experimental practice it is presumably the most relevant question whether these results can be generalized to situations outside the laboratory. In the present studies ecological validity can be estimated to be relatively high. Action execution as it was investigated is not restricted to quite uniform responses such as key-presses but allows for a higher amount of motor activity. Further, performing movements with a computer device is a setting which is also relevant in everyday live for many people these days. Still, there are some points in this artificially setting which might restrict generalizability to actions conducted in everyday live.

First, while moving on a touch-sensitive device has become quite natural, performing continuous-reversal movement is not. Such movements were chosen in order to avoid specific methodological problems that arise with discrete aiming movements towards targets, like for example different workspaces (to or away from the body) or differences resulting from movement sequences (a movement is followed or not followed by another movement). Moreover, performing continuous-reversal movements creates a setting in which stable goal representations can be formed because they were performed very often. Second, in the experimental situation any further context information is absent, a scenario which differs quite substantial from everyday live. It is possible that the context information might play an important role for action execution, for example when performing actions in a familiar or unfamiliar context or sequence. Contexts can be for example the hierarchy of action goals or the complexity of a to be performed sequence (which is especially relevant in the temporal domain, since the interpretation of targets a action goals requires a certain predictability of the temporal goal, which also depends on the complexity of a sequence). Third, the same type of continuous-reversal movement had to be executed in order to move to the different action goals. This was intended as the ratio of the experiments was to compare movements towards different goals. To draw conclusions from similarities and differences of movements towards different action *goals* it was tried to make the *movements* to obtain them as similar as possible. In everyday life it is however more likely that certain movements are normally connected to certain types of action goals. For example, aiming movements with one (the dominant) hand are quite typical for achieving spatial goals, but not so much for achieving temporal goals. On the other hand, synchronization movements as used to achieve temporal goals are often conducted with the whole body, for example when dancing or in bimanual movements, for example when playing the piano. This leads again to the question if the results can be generalized to situations in everyday live. I dare to say with caution that the influence of goal representations on movement kinematics should be the same or should even be stronger in everyday live. The actions in everyday live can be considered to be "more intentional" in the case of novel actions and in case of habitualized actions they are better trained and the action target or effect is well known. Moreover, in everyday life actions are conducted in a context that is meaningful to a person. Since the results obtained in the here presented studies indicate that movement kinematics are shaped to a stronger degree by goals that are represented more precise it can be assumed that more natural circumstances lead to more precise goal representations in many cases and therefore to an even stronger influence of goal representations.

In order to take a few steps further in exploring the role of goal representations in action control and to overcome shortcomings of the here presented studies it would be interesting for future research to address some open questions. For instance, it seems likely that attention plays a crucial role for the influence of goal representations on action execution (for the role of attention for action control see e.g. Hesse, Schenk, & Deubel, 2012; Posner, 2012; Schiegg, Deubel, & Schneider, 2003). It would be interesting to investigate different measurements of attention (like for example with an eye-tracking device) in addition to kinematic variables to see how open measurements of attention are distributed in space. Further, is might also be promising to directly manipulate attention experimentally to investigate its influence on action execution. It can be speculated that the influence of goal representations on action execution varies with attention.

While the here presented studies could show a few interesting results concerning the question how certain goal features are represented this question has not been investigated systematically. A more systematic investigation of the integration of different goal features seems to be promising. Besides a wider and more systematical variation of physical properties of action goals like pitch or saliency, the emotional or semantic context of the experimental setting could also influence goal representations and shape movement kinematics in a distinct manner. For example, targets and effects could be given an emotional appeal by using phobic (like spiders) or neutral stimuli (e.g. Coombes, Gamble, Cauraugh, & Janelle, 2008; Hajcak, Molnar, George, Bolger, Koola, & Nahas, 2007; Duckworth, Barth, Garcia, & Chaiken, 2002) and induce avoidance or attraction. Such semantics should also be integrated in the goal representation and shape kinematics accordingly.

While the just described considerations deal with possible variations of the paradigm used here, there are also broader perspectives which can be considered. The here described studies exclusively dealt with a single person acting in an inanimate environment. However, to provide a full picture of the influence of goal representations on action execution one has to bear in mind that humans live in social environments where interaction with others is unavoidable and acting in dynamic environments is the default mode of acting. We are used to interpret the kinematics of movements we see around us in a specific manner: namely as goal-directed. We infer the underlying cause of movement kinematics we observe and try to guess what the intention of other people´s actions could be. Not only do the kinematics of our own movements reflect rather the *why* and *what for* (instead of the *when* and *where*), we also see "behind" the movement kinematics happening around us and infer the underlying *why* and *what for* (Prinz, 2012). As described above it is considered a necessary prerequisite of ideomotor learning that action and perception share a common representational domain (see chapter 1.2.1). But not only self-produced actions and perceived events are represented in a common representational domain. The same also holds true for one´s own actions and actions that are executed by other persons. This also implies that perceived and produced actions can have a mutual influence on each other: perceived actions can modulate action production, and produced action can modulate action perception. Such a modulation should depend on the representational overlap between perceived and performed actions. Indeed, evidence has been found for both inhibition and facilitation effects of perceived action on action production (e.g. Kilner, Hamilton, and Blakemore, 2007; Prinz, de Maeght, & Knuf, 2005; Brass, Bekkering, & Prinz, 2001), and also of produced actions on event perception (e.g. Jacobs & Shiffrar, 2005; Grosjean, Zwickel, & Prinz, 2009; for an overview see Schütz-Bosbach & Prinz, 2007). Related to this dissertation, it was shown that participants are able to discriminate kinematics of their own actions from other actions (Knoblich & Flach, 2001; 2003). It would be interesting for future research to investigate the influence of a social environment on action execution. It could possibly be for example that observing how another person performs a task similar to the one described here would show an influence on action execution. More complex designs involving cooperation or action perception as independent variables could provide further insight in the role of goal representations in action control.

I. INTRODUCTION

Chapter 2

Target- and effect-directed actions towards temporal goals: Similar mechanisms?

Shortened Title: Temporal Targets and Effects

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Journal of Experimental Psychology: Human Perception and Performance, 2012, 38(4), pp. 958–974.

Abstract

The goal of an action can consist of generating a change in the environment (to produce an effect) or changing one's own situation in the environment (to move to a physical target). To investigate whether the mechanisms of effect-directed and target-directed action control are similar, participants performed continuous reversal movements. They either synchronized movement reversals with regularly presented tones (temporal targets), or produced tones at reversals isochronously (temporal effects). In both goal conditions an irrelevant goal characteristic was integrated into the goal representation (loudness, Experiment 1). When targets and effects were presented within the same reversal movement, similarities were enhanced (Experiment 2). When the task posed spatial demands in addition to temporal demands, target- and effect-directed movement kinematics changed equally with tempo (Experiment 3). Correlations between target-directed and effect-directed movements in temporal variability indicated similar timing mechanisms (Experiments 1 and 2). Only gradual differences between target- and effect-directed movements were observed. We conclude that the same mechanisms of action control, including the anticipation of upcoming events, underlie effect-directed and target-directed movements. Ideomotor theories of action control should incorporate action targets as goals similar to action effects.

1. Introduction

To interact in a meaningful way with the environment we perform goal-directed actions. We press keys on the piano in order to produce music or we time our movements to the rhythm of a tune when dancing. Such action goals fall into two broad categories: First, it can be the goal of an action to generate a change in the environment, i.e. to produce an action effect. For example, a pianist presses a key on the piano and consequently a sound occurs. Second, it can be the goal of an action to change one's own situation in the environment, i.e. to move to a target. An example is dancing to a samba rhythm. In the following, we refer to these different goals of an action as effects and targets, respectively. The term effect-directed action designates that a movement is conducted in order to produce an effect and the term target-directed action designates that a movement is conducted in order to move to a physical target.

From a theoretical viewpoint effect-directed and target-directed actions have similar roles in action control: they are both movements conducted towards goals. In effect-directed actions the goal is the production of the effect and the manipulation of the environment itself. Target-directed actions also entail the representation of action goals such as "to be at a certain place at a given time". In the present paper we are interested in the similarities and differences between target-directed and effect-directed actions and their underlying mechanisms of action control. This was done analyzing *how* participants move towards the respective goals. To this aim, participants performed continuous reversal movements. In effect-directed movements participants produced tones in a regular rhythm at movement reversals, and in target-directed movements participants synchronized movement reversals with tones presented in a regular rhythm. We compared the kinematics of movements generating auditory-temporal effects and the kinematics of movements towards auditory-temporal targets.

Research on effect-directed and target-directed actions is usually conducted in separate, distinct domains. Target-directed actions are most often investigated in tasks requiring synchronization tapping. In such tasks temporal targets (e.g. beats of a metronome) play an important role in movement organization (for an overview see Repp, 2005). When participants synchronize their taps with regular external events, movements preceding the taps are shorter than the movements following the taps, irrespective of whether the taps are achieved by flexion or extension (Balasubramaniam, Wing, & Daffertshofer, 2004; Torre & Balasubramaniam, 2009). Similarly, when participants perform continuous reversal movements using the whole hand, the execution of target-directed movements is influenced by target characteristics: movements towards temporal targets show relatively late and high peak velocity, and relatively short movement times in comparison to movements away from them (Rieger, 2007). Temporal targets can be viewed as events or movement goals structuring an action or a sequence of actions. The relative importance of events within this structure depends on the relative salience of the different events (Ivry, Spencer, Hazeltine, & Semjen, 2004). Stressed/salient events are assumed to be higher hierarchical goals. The kinematic pattern described above is more pronounced, and temporal variability is lower at events higher in the hierarchy (e.g. Kelso, Buchanan & Wallace, 1991; Byblow, Carson, & Goodman, 1994).

Research on effect-directed actions is often conducted in the context of ideomotor approaches of action control. Here the central idea is that an action is initiated by the anticipation of its intended perceptual consequences (James, 1890/1981; Prinz, 1997). Due to associations between movements and their perceivable outcomes ("action-effect bindings", Elsner & Hommel, 2001, 2004; Hommel, Alonso, & Fuentes, 2003) the anticipation of desired effects automatically evokes the appropriate motor commands to produce them (Elsner & Hommel, 2001; Kunde, Hoffmann, & Zellmann, 2002). Several studies addressed the role of action effects for action initiation, selection and execution. It has been shown that after producing auditory action effects for only a few trials (e.g. high tones with a left hand key press and low tones with a right hand key press), the subsequent presentation of these tones primes the respective key presses (Elsner & Hommel, 2001; Kunde, 2004). Correspondingly, in expert pianists the mere perception of sounds from a piano activates and induces the correct finger movements (Drost, Rieger, Brass, Gunter, & Prinz, 2005). Auditory action effects do not only activate and induce actions: their features also influence characteristics of movement execution (Kunde, Koch, & Hoffmann, 2004). Kunde et al. observed that response force is influenced by the intensity of the produced auditory effects: key presses are executed more forcefully when they are followed by a loud tone than when they are followed by a soft tone. A similar pattern of movement kinematics has been found in studies investigating regular rhythmic production of action effects. Accentuated or more salient action effects are produced with faster movements and higher peak velocity than less salient events. For example, Dahl (2000) showed that percussionists produce shortened intervals before playing the accent in comparison to non-accents, and prolonged intervals after an accent. A similar movement pattern was observed in a finger tapping task (Billon, Semjen, & Stelmach, 1996). Further, movements producing temporal effects seem to be executed differently from movements that follow temporal effects. Using a synchronization-continuation paradigm, Doumas & Wing (2007) found that in the continuation phase flexion movements that were necessary to make contact with the response key reached considerably higher velocities and were of shorter duration than the corresponding extension movements. However, flexion and extension movements were not varied systematically and thus the observed pattern may also be explained by anatomical differences between them. Altogether, studies on auditory-temporal action effects show that movement kinematics differ depending on characteristics of the produced effect.

The kinematic pattern when moving to temporal effects seems to be similar to the kinematic pattern when moving to temporal targets. This pattern of relatively short movement duration, and relatively high and late peak velocity, resulting in an asymmetric velocity profile, will be referred to as ‘temporal movement kinematics’ in the following. The similarities between target-directed and effect-directed actions support the assumption that both are represented in a similar way as goal-directed. It should be noted that the observed kinematic pattern occurs *before* the target is reached or the effect is produced, thus showing an influence of upcoming events on movement execution. This indicates that the representation of action goals activates motor commands which produce kinematic patterns that are optimally suited to achieve the goals (Balasubramaniamet al., 2004; Kunde et al., 2004; Repp, 2005; Rieger, 2007; Elliott, Weichmann, & Wing, 2009; Torre & Balasubramaniam 2009).

There are also some differences between effect-directed and target-directed actions. Targets are externally generated and usually present in the environment regardless of what a person does. For example, irrespective of the ability of a person to dance to a rhythm, the rhythm itself remains unchanged. Thus, a presented rhythm -as a temporal target for dance- provides regular and precise temporal information. This information can be used to correct timing errors. In contrast, temporal effects depend on the variability of one's own movement, the accuracy of the internally represented temporal goal, and only occur if the respective movement is actually executed. Without the possibility to compare one's own timing to an external event timing errors influence subsequent timing performance. In synchronization-continuation tapping temporal variability increases once the task switches from synchronization (with a metronome) to continuation (without a metronome, Ruspantini & Christolini, 2009; Vardy, Daffertshofer, & Beek, 2009). This phenomenon, known as drift, leads to more variable tapping behavior, which increases as to be produced execution rates decrease, and can be observed even in experienced musicians (Collier & Ogden, 2004).

To sum up, there is evidence that target-directed and effect-directed actions may be controlled in similar ways, i.e. movement trajectories seem to have similar shapes. Previous studies also point to some possible differences, especially in timing precision. However, to the best of our knowledge movement kinematics of target-directed and effect-directed actions have not yet been compared directly in previous studies. In studies using synchronization-continuation paradigms the continuation condition (which can be compared to effect-directed movements) always follows the synchronization condition (which can be compared to target-directed movements). This order may influence the kinematic pattern observed in the continuation phase. Further, the kinematics of the synchronization and the continuation phase have not been compared directly, but have only been analyzed within phases (continuation: Doumas & Wing, 2007; synchronization: Torre & Balasubramaniam, 2009). In addition, the metronome is switched off in the continuation phase, rather than that a beat is produced by the tapping movements. Thus, the temporal target in the synchronization phase (time of contact with a surface and a beat) is different from the temporal effect in the continuation phase (time of contact with a surface). In fact, adding auditory feedback in the continuation phase increases the similarity between synchronization and continuation concerning temporal consistency (Flach, 2005). Another difference between studies analyzing effect-directed and target-directed movements is the movement format. In studies on effect-directed actions usually movements in which contact with a surface is made (Billon et al., 1996; Dahl, 2000; Doumas & Wing, 2007) are investigated. In studies on target-directed actions not only spatially restricted, but also spatially unrestricted movements have been investigated (Balasubramaniam et al., 2004; Torre &Balasubramaniam 2009; Rieger, 2007).

Thus, in the present study we were interested in the question whether the execution of target-directed and effect-directed actions is controlled in similar ways through representations of intentional action goals, which influence the preceding movement. If this is the case, the ideomotor theory of action control can be applied to targets, as well as effects. To this aim we investigated in three experiments similarities and differences in movement kinematics between target-directed and effect-directed movements in a task in which auditory-temporal targets and effects are as similar as possible, and movements towards both types of goals are performed under comparable conditions.

2. General Method

2.1. Participants

Participants had to be right-handed according to the Edinburgh Inventory (Oldfield, 1971), and had to have normal or corrected-to-normal vision. They gave informed consent prior to the experiments and received 7 Euro per hour for participation. None of the participants took part in more than one experiment.

2.2. Materials, Apparatus and Procedure

Movements were recorded using a 30.5 cm x 45.5 cm Wacom Ultrapad A3 writing pad at a resolution of 500 pixels per cm and at a rate of 172 Hz that was placed on a desk. A cover shielded the right hand from view. Participants saw their movement trace consisting of a blue circle (4 mm in diameter) on a screen (17´´, resolution: 1024 x 768 pixels, vertical refresh rate: 100 Hz). Movement distance on the writing pad equaled movement distance on screen. The screen was placed behind the pad (60 cm away from the participants) and 9 cm higher. Standard temporal targets and effects consisted of 1000 Hz tones (54 dB) presented for 5 ms through loudspeakers placed to the left and the right of the screen. The software Presentation 14.1 was used for stimulus presentation and data recording.

Participants were asked to perform continuous reversal movements on the medial-lateral axis without pausing at the reversal points, i.e. to move continuously back and forth on the pad with a pen (see Figure 2.1) in different tempi. They were asked either to synchronize the movement reversals with tones presented in a regular isochronous rhythm (i.e. target-directed movements) or to produce tones in the same regular isochronous rhythm at movement reversals (i.e. effect-directed movements). Movement reversals were detected online by the program on average after 5.8 ms. Thus, the tone was presented on average 5.8 ms after participants reversed the movement in effect conditions.

At the beginning of each experiment participants received general instructions presented on the screen explaining all conditions. Detailed instructions were presented before each trial. Instructions included a black line of 10.6 cm length aligned horizontally in the middle of the screen and a red box (0.5 x 0.5 cm). Participants were instructed to perform movements of the approximate length of this line. When participants started the trial by entering the red box with their pen the screen went blank. Trial duration was always 40 seconds. Demonstrations of the regular rhythm before trials had a duration of 8 seconds. Participants were instructed to listen to the rhythm without moving and to keep it vividly in mind. During the experimental trials they were asked to produce the tones in the same rhythm at movement reversals or to synchronize movement reversals with the rhythm.

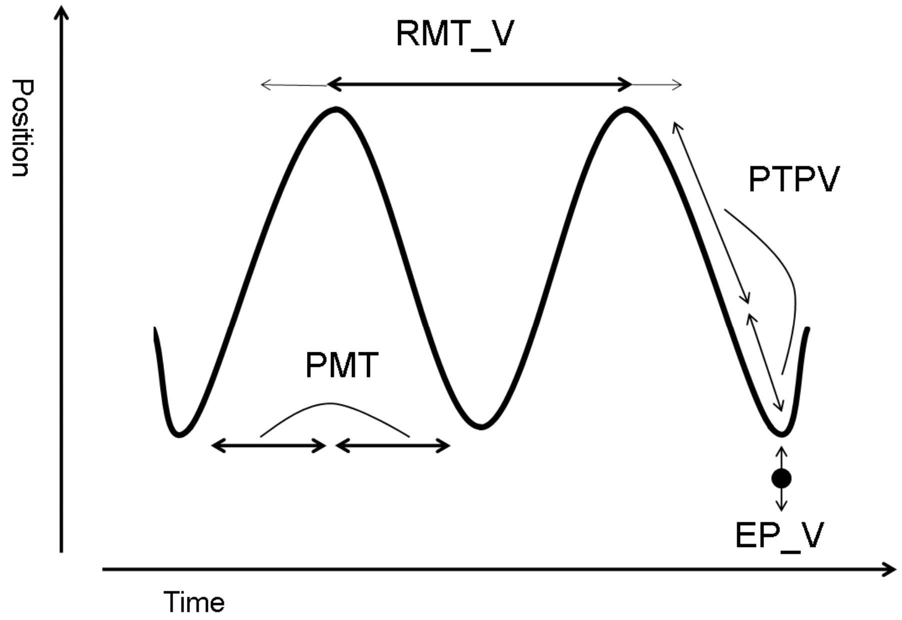

Figure 2.1. Example of a complete reversal movement and graphical overview of analyzed dependent variables. One oscillation, i.e. one complete to and from movement, represents a movement reversal. The following dependent variables were analyzed in all three experiments. PTPV = proportional time to peak velocity, i.e. the point in time, where peak velocity occurs relative to the duration of a complete movement; PMT = proportional movement time, i.e. the time spent on one movement relative to the time for a complete reversal movement; RMT_V = reversal movement time variability, i.e. the variability around the average duration of a movement; EP_V = endpoint variability, i.e. the variability around the average endpoint of a movement on the x-axis.

2.3. Data Analysis

Raw data were smoothed with a nonlinear smoothing algorithm (Mottet, Bardy, & Athenes, 1994) by using weighted and moving medians in a 7 data point window. After that, pen velocity was determined at each measured point in time (i.e. every 5.8 ms) and then smoothed with the same algorithm. The first 10 seconds of each trial were excluded from further analyses. Since displacements on the y-axis were small

(Experiment 1: M = 0.28 cm, SE = 0.001 cm; Experiment 2: M = 0.3 cm, SE = 0.001 cm; Experiment 3: M = 0.52 cm, SE = 0.003 cm), only the maximum displacements on the x-axis were analyzed.

The reversal points (onsets and endpoints of a movement in one direction) were defined as the most leftwards/rightwards points of a movement followed by one data point (offline analyses: two data points) indicating that the movement direction had changed. Movements were excluded from analysis if a) participants did not move continuously (not more than 1 mm within the first 50 ms of a movement), b) movement length was smaller than 2.7 cm (i.e. a quarter of the instructed approximate length), or c) movement time was more than two standard deviations longer or shorter than the individually calculated z-standardized values of movement time in each condition. Because there were no differences in the data patterns between movements to the left and to the right, data were collapsed over the two sides.

The following variables were analyzed in all three experiments (for a graphical overview see Figure 2.1). To analyze the shape of trajectory the time to reach peak velocity relative to the complete duration of the movement (proportional time to peak velocity in %, PTPV) and the time spent on one movement relative to the time spent on the complete reversal movement (proportional movement time in %, PMT) were analyzed as dependent variables. To characterize temporal and spatial variability, the variability around the average time of a reversal movement (reversal movement time variability in ms, RMT_V) and the variability around the average endpoint of the movements in the x-axis (endpoint variability in cm, EP_V) were analyzed. In order to evaluate whether target-and effect-directed movements are similar in other aspects which might lead to differences in the variables of interest, we calculated the duration of a whole reversal movement (in ms, RMT), and movement amplitude on the x-axis (in cm, MA) as control variables. We only focus on differences between target- and effect-directed movements in the analyses of those two variables (data are presented as supplementary material at the end of this chapter). Further, because effects were presented 5.8 ms after the outermost position of a movement was reached, we also analyzed asynchronies (A) of target conditions as a control variable in Experiment 1. We did however not expect that the tone would occur later in effect than in target directed movements, because negative asynchronies (i.e. a tap preceding the tone of a regularly presented rhythm) are a well-known phenomenon in the tapping literature (for a review see Aschersleben, 2002). We also calculated Pearson correlation coefficients of RMT_V of effect and target conditions. This was done because if individual differences in temporal variability lead to positive correlation coefficients across tasks one can conclude that timing performance is not task specific, but that common timing mechanisms are effective (Zelzanik et al., 2005; correlation tables for Experiments 2 and 3 can be found as supplementary material at the end of this chapter).

The following statistical procedures were applied: a) if Mauchly´s test indicated that the assumption of sphericity was violated we report Greenhouse-Geisser corrected *F*-values (Greenhouse-Geisser´ε is then reported in parenthesis), b) only higher order effects are reported if the lower order effects cannot be interpreted on their own c) significant effects were further analyzed using paired-sample *t*-Tests and Post-Hoc analyses using multiple comparisons (Bonferroni corrected *p*-values are reported).

3. Experiment 1

Temporal goals were presented in three different goal sets (see Figure 2.2, Row 1). On one side of the movement, always the same standard tone was presented. On the other side there was a) no tone (one goal set), b) the same standard tone (same goals set) or c) a louder tone (different goals set).

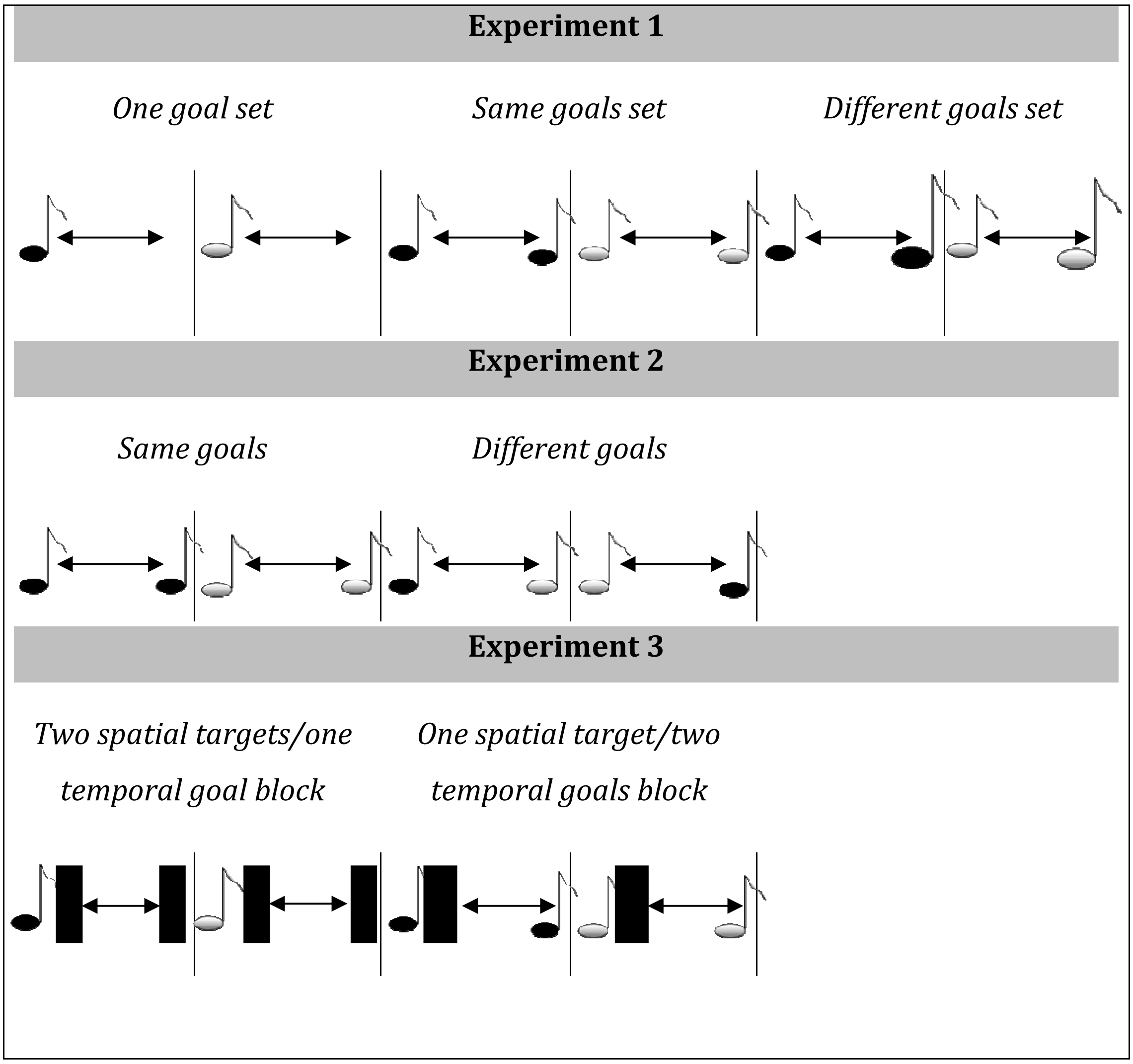

Figure 2.2. Graphical overview of the different goal sets in all 3 experiments. Black objects represent targets, grey objects represent effects. Notes represent temporal targets/effects. Small notes represent the standard tone (55 dB), large notes loud tones (75 dB). Boxes represent spatial targets. In target-directed actions participants were asked to synchronize movement reversals with presented tones. In effect-directed actions participants were asked to produce tones at movement reversals. If visual targets were present (Experiment 3) participants were additionally asked to reverse their movements on presented boxes.

Because we assume that both targets and effects function as action goals, and thus similar control mechanisms underlie goal-directed actions towards targets and effects, we expected to observe similar kinematic patterns in target and effect conditions (goal condition).

In the one goal set we expected to observe a more pronounced temporal kinematic pattern (higher PTPV, lower PMT) in movements towards targets/effects than in movements towards the side without targets/effects. No such differences should be present in the same goals set. In the different goals set the effect/target tones can be encoded on two dimensions: the time of occurrence or target interval (relevant for the production of a regular rhythm) and the loudness (irrelevant for the task). The louder tone should be more salient in the event structure, and represent a higher hierarchical action goal (Ivry et al., 2004). Therefore movements towards the louder goal should show a more pronounced temporal kinematic pattern (higher PTPV, lower PMT) compared to movements towards the standard goal in the different goals set. This should be the case for target-directed as well as effect-directed movements if they are similarily represented as temporal goals. However, in effect-directed actions the need to entirely rely on the internal generation of the rhythm may require that more cognitive resources are devoted to timing which may leave less capacity for the representation of other (irrelevant) goal features like loudness. This may result in similar kinematics towards the tones of different loudness within the effect condition (about 50% PMT, no difference in PTPV).

We assumed that spatial variability in target-directed and effect-directed movements is similar (no differences in EP_V). However, because temporal variability usually increases without a pacing signal (Ruspantini & Christolini, 2009; Vardy et al., 2009), we expected to observe higher temporal variability (higher RMT_V) in effect conditions than in target conditions. We further expected that if similar timing mechanisms underlie target-directed and effect-directed actions correlations of RMT_V between effect-directed and target-directed movements for each tempo and both reversal sides should be positive and significant.

3.1. Method

3.1.1. Participants

19 participants (9 female; mean age = 25.1 years, *SD* = 3.5) with a mean laterality quotient of 90 (*SD* = 12) took part.

3.1.2. Materials, Apparatus and Procedure

Auditory stimuli consisted of the standard tone (54 dB) and a louder tone (74 dB). A complete reversal movement was conducted in two different tempi: 750 ms tempo (1.3 Hz) and 1250 ms tempo (0.8 Hz). Participants received four training trials at tempo 1000 ms for a complete reversal.

The combination of three different goal sets and two goal conditions with two tempi, together with the balancing of the location (left, right) of the goals resulted in 24 experimental trials (in the same goals set the same number of trials was conducted). These 24 trials were presented two times in random order (restriction: not more than three trials of the same tempo or the same goal condition in a row) interrupted by a short break. The experiment took approximately one hour.

3.1.3. Data Analysis

Between 2% and 5% of movements were excluded from analyses in each condition. Data were subjected to 3 x 2 x 2 x 2 factors repeated measurements analyses of variances (ANOVAs) with the factors GoalSet (one goal, same goals, different goals), GoalCondition (target, effect), Tempo (750 ms, 1250 ms), and ReversalSide (standard tone, manipulated side). Note that the manipulated side can consist of no tone (one goal set), the standard tone (same goals set), or a louder tone (different goals set). RMT and MA were subjected to 3 x 2 x 2 factors repeated measurement ANOVAs with the factors GoalSet (one goal, same goals, different goals), GoalCondition (target, effect), and Tempo (750 ms, 1250 ms). The average A of target conditions was compared to the A of -5.8 ms of effect conditions using a paired samples t-Test.

3.2. *Results*

3.2.1. Shape of trajectory

Proportional time to peak velocity (PTPV, see Figure 2.3, Panel A). A significant main effect of GoalCondition, $F(1, 18) = 10.64$, $MSE = 57.00$, $p = .004$, indicated that effect-directed movements have lower PTPV (M = 48.1%) than target-directed movements (M = 50.4%). However, no significant interactions with the factor GoalCondition were observed, indicating that data patterns were similar for target-directed and effect-directed movements.

The significant GoalSet x ReversalSide interaction, $F(2, 36) = 19.60$, $MSE = 58.07$, $p < .001$ ($\varepsilon = 0.72$), reflects that in the one goal set movements towards the standard tone had a higher PTPV (M = 51.5%) than movements to the other side without a tone (M = 45.4%, $t(18) = 3.21$, $p = .005$). The reverse pattern was observed for movements in the different goals set: movements towards the louder tone (M = 51.2%) have a higher PTPV than movements towards the standard tone (M = 48.37%, $t(18) = 2.52$, $p = .021$). In the same goals set no difference in PTPV between movements to the two sides was observed, $t(18) = 1.27$, $p = .220$.

We also obtained a significant GoalSet x Tempo x ReversalSide interaction, $F(2, 36) = 5.96$, $MSE = 18.34$, $p = .012$ ($\varepsilon = 0.76$). The differences between movements towards the standard tone and the other side are higher in slow tempo (7.5%) than in fast tempo (3.5%, $t(18) = 3.1$, $p = .006$) in the one goal set, but they do not vary with tempo in the different goals set (3.4% in slow tempo and 2.6% in fast tempo, $t(18) = 0.16$, $p = .877$).

Proportional movement time (PMT, see Figure 2.3, Panel B). Only the GoalSet x ReversalSide interaction, $F(2, 36) = 9.84$, $MSE = 17.84$, $p = .005$ ($\varepsilon = 0.53$), reached significance. In the one goal set moving towards the standard tone resulted in lower PMT (M = 49%) than moving away from it to the no-tone side (M = 51%, $t(18) = 3.18$, $p = .005$). In the different goals set moving towards the louder tone (M = 49.4%) resulted in lower PMT than moving towards the standard tone (M = 50.6%, $t(18) = 3.11$, $p = .006$).

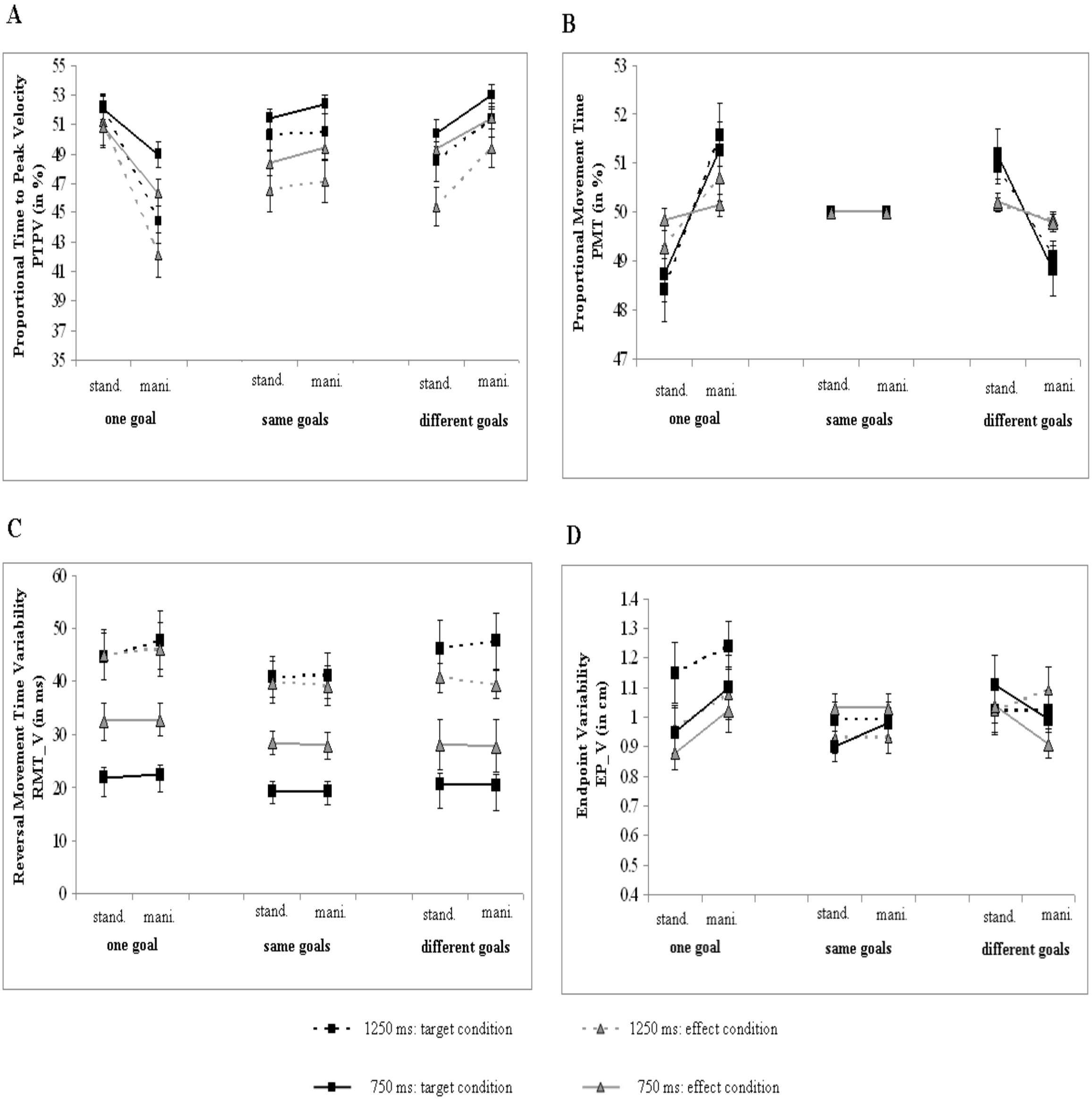

Figure 2.3. Experiment 1 (stand = standard tone, mani = manipulated side): Means and standard errors (error bars represent +/- 1 SE) of proportional time to peak velocity in % (PTPV, Panel A), proportional movement time in % (PMT, Panel B), Reversal Movement Time Variability in ms (RMT_V, Panel C) and Endpoint Variability in cm (EP_V, Panel D).

3.2.2. Temporal performance

Reversal movement time variability (RMT_V, see Figure 2.3, Panel C). There was a main effect of GoalSet, $F(2, 36) = 4.94$, $MSE = 239.14$, $p = .013$, showing that RMT_V was higher in one goal set ($M = 37$ ms) than in the same goals sets ($M = 32$ ms, $p = .027$). The main effect of Tempo, $F(2, 36) = 73.8$, $MSE = 503.03$, $p < .001$ shows that RMT_V is higher in slow ($M = 43$ ms) than in fast tempo ($M = 25$ ms). There was also a significant GoalCondition x Tempo interaction, $F(1, 18) = 21.43$, $MSE = 180.06$, $p < .001$. In fast tempo target-directed movements ($M = 21$ ms) have a lower RMT_V than effect-directed movements ($M = 30$ ms, $t(18) = 5.71$, $p < .001$. In slow tempo RMT_V did not significantly differ between goal conditions, $t(18) = 1.29$, $p = .215$.

Reversal movement time. (RMT). An interaction of GoalCondition x Tempo, $F(1, 18) = 8.87$, $MSE = 5077.35$, $p = .008$, reflected that in fast tempo target-directed movements ($M = 753$ ms) had lower RMT than effect-directed movements ($M = 797$ ms, $t(18) = 4.18$, $p < .001$). This might explain that target-directed movements show lower RMT_V than effect-directed movements (see discussion).

Asynchronies (A). A ranged from -21.3 ms to 2.4 ms in target-directed movements ($M = -7.13$ ms). Thus, the occurrence of movement reversals relative to the tones was not earlier in effect ($M = -5.8$ ms) than in target conditions, $t(18) = 0.51$, $p = .62$.

Pearson correlations of RMT_V (see Table 2.1). Correlations between target-directed and effect-directed movements were positive in all conditions. All but two correlations were significant.

Table 2.1. Experiment 1: Pearson correlations coefficients between temporal variability (RMT_V) of target-directed and effect-directed movements for every GoalSet in each Tempo, and for each ReversalSide.

	One goal		Same goals		Different goals	
	Standard	None	Standard	Standard	Standard	Loud
1250 ms tempo	.709**	.867**	.571*	.599**	.477*	.367
750 ms tempo	.306	.212	.669**	.576**	.577**	.599*

*Note: * p < .05; ** p < .01*

3.2.3. Spatial performance

Endpoint variability (EP_V, see Figure 2.3, Panel D). A significant GoalSet x Tempo interaction, $F(2, 36) = 3.38$, $MSE = 0.67$, $p = .045$, reflected that in the one goal set EP_V was higher in slow tempo ($M = 1.1$ cm) than in fast tempo ($M = 1$ cm, $t(18) = 2.39$, $p = .028$), while in the other two goal sets tempo had no effect on EP_V (same goals: $t(18) = 0.95$, $p = .358$; different goals: $t(18) = 0.66$, $p = .52$).

Movement amplitude on the x-axis. (MA). Mean MA values ranged from 10.2 cm to 11.6 cm, indicating the participants follow the instruction to move in the approximately length of 10.6 cm quite well ($M = 10.8$ cm, $SE = 0.01$ cm). There was a GoalSet x GoalCondition interaction, $F(2, 36) = 5.95$, $MSE = 0.82$, $p = .013$ ($\varepsilon =$

0.73), reflecting that in the same goals set MA is higher in target-directed (*M* =11.5 cm) than in effect-directed movements (*M* = 10.8 cm, *t*(18) = 3.32, *p* = .004).

3.3. Discussion

In Experiment 1 we investigated whether similar mechanisms of action control regulate movements towards presented auditory-temporal targets and self-produced auditory-temporal effects. Overall the data indicate that target-directed and effect-directed movements are performed in a similar way: no interactions with GoalCondition were observed in PTPV, PMT and EP_V. A typical relative temporal kinematic pattern was observed in the one goal set: movements towards the goal side had lower PMT and higher PTPV than movements to the no-goal side. Moreover, in the different goals set movements towards the louder tone also showed lower PMT and higher PTPV than movements towards the standard tone. In both cases the relative temporal kinematics were observed in target-directed and in effect-directed movements. Further, RMT_V of target- and effect-directed movements was positively correlated indicating that similar timing mechanisms contributed to performance in both conditions. However, subtle differences between target- and effect-directed movements were also observed: in effect-directed movements PTPV is overall lower than in target-directed movements. Also, at fast tempo target-directed movements had lower RMT_V than effect-directed movements. Participants' movements had longer MA in target-directed movements in same goals set than in all other conditions, even though they moved in the requested tempo.

In accordance with our hypothesis the data indicate that target-directed and effect directed movements are performed in a similar way with respect to the shape of movement trajectories across the different conditions. Both target- and effect-directed movements show a temporal kinematic pattern (higher PTPV, lower PMT) towards temporal goals compared to movements towards the reversal side without a goal. This is in accordance with previous studies which have described this specific kinematic pattern for movements towards temporal targets and similarly for movements towards temporal effects (Billon et al., 1996; Dahl, 2000; Balasubramaniam et al., 2004; Doumas & Wing, 2007; Rieger, 2007; Torre & Balasubramaniam, 2009). It is assumed that this temporal asymmetry *to* and *away* from the temporal goal may be used for the correction of consecutive asynchronies and may help to achieve the timing demands of the task most accurately (Torre & Balasubramaniam, 2009). Similarly, the loudness manipulation in the different-goals set led to a stronger representation (i.e. more pronounced temporal kinematics) of the louder tone compared to the standard tone. This is consistent with the event-structure account, in which more salient events are major hierarchical goals (Semjen, 2002; Ivry et al., 2004). Thus, participants integrated the task-irrelevant goal-feature of loudness into the goal representation in both goal conditions.

Because this general pattern described was observed in both goal conditions, the representation of the temporal goal shapes movement trajectory (cf. Rieger, 2007) and not whether the goal consists of a target or an effect. In both cases the internal clock provides temporal goals at which movements produce their meaningful effects (Billon et al., 1996; Jirsa, Fink, Foo, & Kelso, 2000; Ivry et al., 2004). In the case of target-directed movements the anticipation to be in synchrony with the event can be interpreted as the meaningful effect, while in the case of effect-directed movements it is the anticipation of the auditory consequences of the movement (Aschersleben, 2002; Kunde et al., 2004).

Not only were target-directed and effect-directed movements performed in similar ways, but there was also evidence for similar timing mechanisms (positive correlations between effect-directed and target-directed movements in RMT_V, cf. Vardy et al., 2009; Zelzanik, Spencer, & Ivry, 2002). Thus, besides the similarity in shape of trajectory the similarity in timing mechanisms points to similar representations of targets and effects as temporal goals.

Differences between target- and effect-directed movements were also observed. Effect-directed movements show lower PTPV than target-directed movements. This indicates that the temporal kinematic pattern is less pronounced in effect-directed movements. Lower MA for effect-directed movements in same goals set may signify higher task difficulty. RMT_V was higher in effect than in target conditions at fast tempo. However, RMT was also higher in effect conditions than in target conditions with fast tempo. Previous studies have shown that temporal variability is positively related to movement time (Schmidt, Zelzanik, Hawkins, Frank, & Quinn, 1979). Therefore differences in movement speed may explain the increased temporal variability in effect-directed movements. Thus, there is no clear evidence that RMT_V is actually higher in effect-directed movements.

In summary, the similar movement kinematics and similarities in timing suggest that the underlying control mechanisms in target- and effect-directed movements are similar. Both targets and effects can be seen as goals of actions influencing the execution of the preceding movement. However, in effect-directed movements the goal representation may be weaker than in target-directed movements, resulting in less pronounced overall kinematic pattern. Irrelevant goal features, such as the loudness of the tone, are integrated into target as well as effect representations. Correspondingly, typical temporal kinematic patterns were observed towards goals (targets and effects) that are assumed to be higher in the goal-hierarchy.

4. Experiment 2

The results of Experiment 1 indicated similar mechanisms of control in target-directed and effect-directed movements. However, there was also some evidence that goal representations might be less pronounced in effect conditions, resulting in a weaker temporal kinematic pattern. Whereas in Experiment 1 movements towards targets and effects were compared across goal sets, we combined them within goal sets in Experiment 2. We expected that a direct comparison of target- and effect-directed movements within one condition may enhance differences between them. Further, this setup prevents that participants move at different overall speed levels in effect-directed and target-directed movements, which was a problem for the interpretation of RMT_V at fast speed in Experiment 1.

Four different goal sets were presented (see Figure 2.2, Row 2): Two with same goals which were a) target-directed movements to both reversal sides (target condition), and b) effect-direct movements to both reversal sides (effect condition), and two with different goals which were c) target-directed movements to the left and effect-directed movements to the right side, and d) target-directed movements to the right and effect-directed movements to the left side. Because tempo modified the strength of the temporal kinematic pattern in Experiment 1 we included three different tempi.

We expected that when participants move towards a temporal target at one side and produce a temporal effect at the other side of the reversal movement, the goal representation for the temporal target may be more pronounced, resulting in a stronger temporal kinematic pattern (higher PTPV, lower PMT). We further expected that when the same type of movement is conducted towards both sides no differences in movement a kinematics towards the sides should occur (PMT 50%).

4.1. Method

4.1.1. Participants

24 participants (13 female; mean age = 24.2 years, SD = 3.0) with a mean laterality quotient of 95 (*SD* = 9) took part.

4.1.2. Materials, Apparatus and Procedure

Each goal set was performed in three tempi for a complete reversal movement: 750 ms (1.3 Hz), 1000 ms (1 Hz), and 1250 ms (0.8 Hz). In the same goals set each tempo was conducted 3 times, in the different goals set 4 times. This additional trial was conducted in order to obtain approximately the same number of analyzable movements in the different goals set, as informal pretests have shown that the different goals set is more difficult. The order of conditions was counterbalanced across participants. Within a condition one tempo was conducted in consecutive trials, while the order of tempi was randomized within conditions. The experiment took approximately 45 minutes.

4.1.3. Data Analysis

The first trial of each tempo in each condition served as a training trial. Between 4% and 5% of movements in each condition were excluded from data analysis. Data were analyzed using repeated measurement ANOVAs with the factors GoalSet (same goals, different goals), GoalCondition (target, effect) and Tempo (750 ms, 1000 ms, and 1250 ms). RMT and MA were subjected to 3 x 3 factors ANOVAs with the factors Goals (targets, effects, different goals) and Tempo (750 ms, 1000 ms, 1250 ms).

4.2. *Results*

4.2.1. Shape of Trajectory

Proportional time to peak velocity (PTPV, see Figure 2.4, Panel A). Only the main effect of Tempo became significant, $F(2, 46) = 7.75$, $MSE = 41.53$, $p < .001$ ($\varepsilon = 0.64$). Peak velocity occurred later with increasing tempo (1250 ms: $M = 46.9\%$; 1000 ms: $M = 48.4\%$; 750 ms: $M = 50.6\%$). Data were intransitive, only the difference between slow tempo and fast tempo became significant ($p = .02$).

Proportional movement time (PMT, see Figure 2.4, Panel B). None of the main effects or interactions became significant. Thus, movement time was distributed evenly between the two sides of the reversal movement in all conditions.

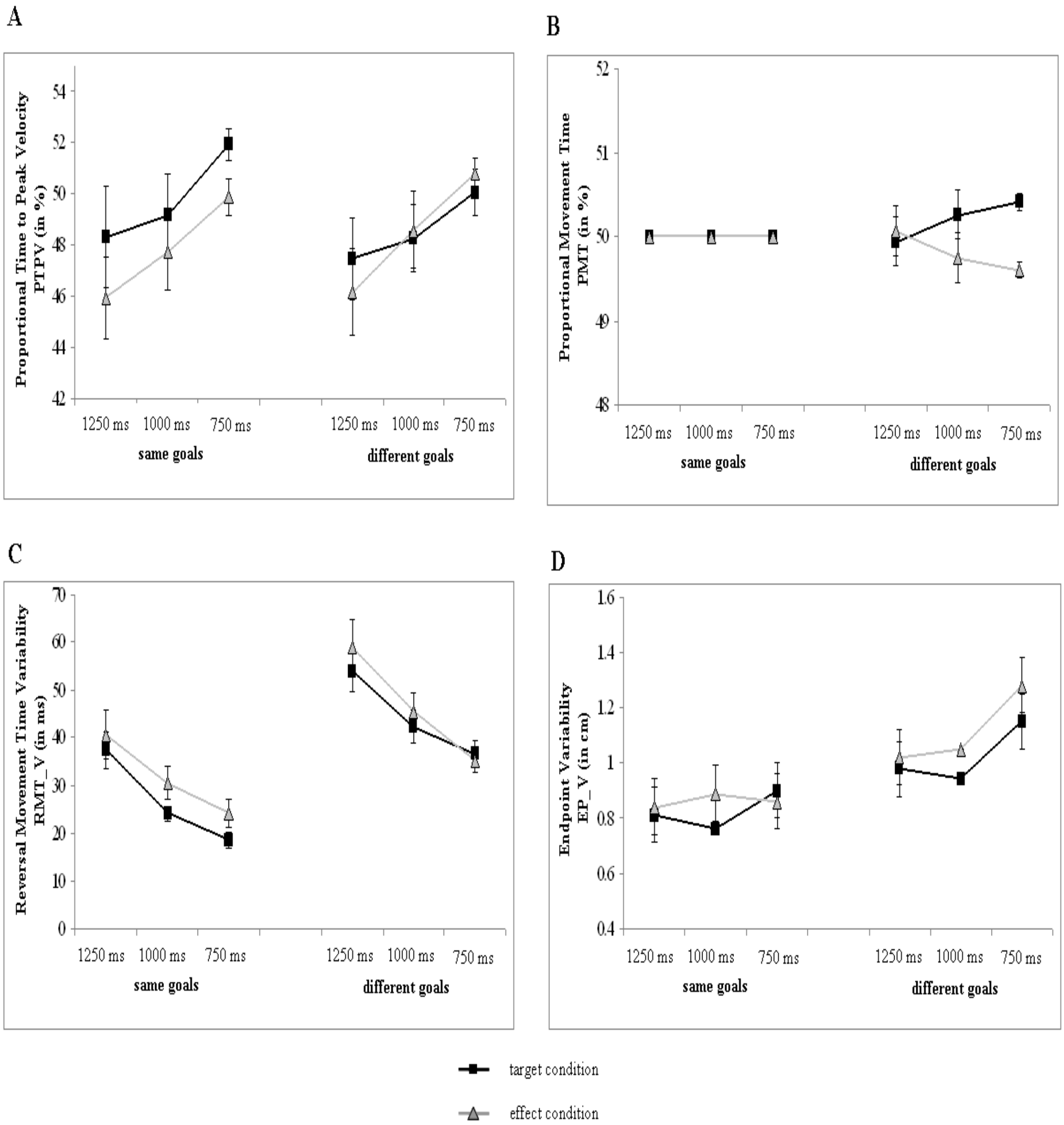

Figure 2.4. Experiment 2: Means and standard errors (error bars represent +/- 1 SE) of proportional time to peak velocity in % (PTPV, Panel A), proportional movement time in % (PMT, Panel B), Reversal Movement Time Variability in ms (RMT_V, Panel C) and Endpoint Variability in cm (EP_V, Panel D).

4.2.2. Temporal performance

Reversal movement time variability (RMT_V, see Figure 2.4, Panel C). There was a significant main effect of GoalSet, $F(1, 23) = 41.88$, $MSE = 449.61$, $p < .001$, indicating the RMT_V was higher with different goals ($M = 46$ ms) than with same goals ($M = 29$ ms). There was also a significant main effect of GoalCondition, $F(1, 23) = 9.92$, $MSE = 94.86$, $p = .004$, indicating higher RMT_V in effect-directed movements ($M = 39$ ms) than in target-directed movements ($M = 36$ ms). The significant main effect of Tempo, $F(2, 46) = 28.31$, $MSE = 526.06$, $p < .001$ ($\varepsilon = 0.58$), indicated again that RMT_V decreased significantly with increasing tempo (1250 ms: $M = 48$ ms; 1000 ms: $M = 36$ ms; 750 ms: $M = 29$ ms, all $p < .001$).

Reversal movement time (RMT). There was a main effect of Goals, $F(1, 23) = 5.64$, $MSE = 3005.81$, $p = .026$. RMT was longer in the targets condition ($M = 1003$ ms) than the different-goals condition ($M = 987$ ms, $p = .025$).

Pearson correlations of RMT_V. Correlations of target- and effect-directed movements of the same goals set with target- and effect-directed movements of the different goals set were all positive and significant, except for some correlations in fast tempo which failed to reach significance (range: $r = .221$ to $r = .715$). This might be due to lower between participants variability with fast tempo.

4.2.3. Spatial performance

Endpoint variability (EP_V, see Figure 2.4, Panel D). A significant main effect of GoalSet, $F(1, 23) = 23.39$, $MSE = 0.16$, $p < .001$, showed that in the same goals set EP_V was lower ($M = 0.8$ cm) than in the different-goals set ($M = 1.1$ cm). There was also a significant main effect of Tempo, $F(2, 46) = 5.2$, $MSE = 0.11$, $p = .009$, showing that EP_V was lower at medium ($M = 0.9$ cm) than at fast tempo ($M = 1.1$ cm, $p = .02$).

Movement amplitude on the x axis. (MA). MA values ranged from 9.9 cm to 11.2 cm ($M = 10.3$, $SE = 0.01$). There was a significant Goals x Tempo interaction, $F(4, 92) = 2.58$, $MSE = 0.78$, $p = .042$. In the effects condition MA was shorter in the 750 ms tempo condition ($M = 10.1$ cm) than in the 1000 ms tempo condition ($M = 10.9$ cm, $t(23) = 2.31$, $p = .03$), and the 1250 ms tempo condition ($M = 10.8$ cm, $t(23) = 2.07$, $p = .05$).

4.3. Discussion

In order to enhance differences between effect-directed and target-directed movements, they were executed within the same condition in Experiment 2. The results show that trajectories are equally shaped in both goal conditions and in both goal sets (no significant differences in PMT and PPTV). Further, correlations between target-directed and effect-directed movements (as well as correlations of movements towards the same goal across goal sets) were mostly positive and significant. However, effect-directed movements have higher RMT_V than target-directed movements in all tempi. RMT_V was higher in slower tempi than in faster tempi, whereas the reverse was the case for EP_V. Both RMT_V and EP_V were higher in the different than in the same goals set.

By comparing target-directed and effect-directed movements within goal sets, we wanted to enhance differences between movements towards them. However, no differences in shape of trajectory between the goal conditions were observed. It seems that rather than enhancing differences between the movements to targets and effects, the task we employed reduced the differences between them with respect to the shape of the trajectory. It seems likely that in the different goals set participants represented targets and effects as belonging to one and the same rhythm, as target and effects tones did not differ from each other in their physical characteristics (i.e. loudness, pitch). The observation that movement trajectories of target- and effect-directed movements are similar in their shape and their timing mechanisms (as indicated by the positive correlations of temporal variability) can thus be seen as further evidence for the functional equivalence of targets and effects as action goals.

One difference between goal conditions was observed: effect-directed movements had higher RMT_V. This was expected because in effect directed-movements participants have to rely on the internally generated rhythm, which is therefore not perfectly isochronous. As a consequence error correction depends on this self-produced variability leading to a greater temporal variability. RMT_V and EP_V were higher in the different goals set than in the same goals set. This may reflect an increased difficulty in this condition due to the need to integrate the internally generated rhythm with the externally presented rhythm.

In summary, the results of experiment 2 strengthen the assumptions that target-directed and effect-directed movements are governed by similar mechanism of control. However, effect-directed movements seem to be temporally more variable than target-directed movements.

5. Experiment 3

Although differences between target- and effect-directed movements were observed with respect to temporal variability in Experiment 2, we failed to enhance differences between them concerning the shape of the trajectory. We therefore adopted a different strategy in Experiment 3 to test the limits of the equivalence of target-directed and effect-directed movements. Not only movements towards temporal targets have a characteristic movement pattern, but also movements towards spatial targets (Rieger, 2007). This spatial kinematic pattern is characterized by relatively long movement times and early peak velocity. Further, certain combinations of spatial and temporal targets lead to different movement patterns with different tempi (spatial or temporal kinematic pattern), reflecting limitations of the cognitive-motor system in meeting both spatial and temporal goals at the same time. It could be that these limitations influence target- and effect-directed movements to a different degree. Therefore we adopted a design in which spatial targets were combined with temporal targets or effects in Experiment 3.

Participants performed continuous reversal movements in two different experimental blocks (see Figure 2.1, Row 3): a) two spatial targets/one temporal goal block: spatial targets on both reversal sides, and an additional temporal goal (target or effect) on one side, and b) one spatial target/two temporal goals block: a spatial target on one reversal side, and additional temporal goals (targets or effects) on both sides. Thus, on one side of the reversal there was always a combined goal (spatial target and temporal goal), on the other side there was a single goal (spatial target or temporal goal). We had five different tempi for a complete reversal movement in this experiment.

It can be assumed that the combined goal will be represented as the hierarchically higher goal (cf. Rieger, 2007). Because it is more difficult to meet spatial and temporal goals at the same time at fast speed, fast movements should show temporal kinematics (higher PTPV, lower PMT) towards the combined goal. In contrast, slow movements should show spatial movement kinematics (lower PTPV, higher PMT) towards the combined goal (Rieger, 2007). We expected to observe a similar pattern in the present experiment irrespective of whether target-directed or effect-directed movements are performed.

However, the different kinds of information temporal targets and effects provide could lead to a modulation of this general pattern. On the one hand, the higher processing demands in effect conditions may leave less capacity to incorporate spatial aspects of the tasks resulting in a more pronounced temporal kinematic pattern. If this is the case, spatial kinematics (lower PTPV, higher PMT) towards the combined goal should occur at s*lower* tempi in the effect condition than in the target condition. On the other hand, as the results from Experiments 1 and 2 indicate, higher processing demands of synchronizing with an internally generated rhythm seem to result in a less pronounced temporal kinematic pattern. If this is the case, reduced temporal kinematics (lower PTPV, higher PMT) towards the combined goal should occur at *faster* tempi in the effect condition. Further, the temporal effect condition allows for more temporal variability than the target condition. Thus it may be easier to incorporate spatial aspects of the task, resulting in a spatial kinematic pattern (lower EP_V, lower PTPV, higher PMT) at *faster* tempi in the effect condition than in the target condition. Note that empirically similar data patterns are expected if effect conditions simply result in a reduced temporal kinematic pattern and if they allow for an easier incorporation of spatial targets.

5.1. *Method*

5.1.1. Participants

24 participants (12 female; mean age = 24.5 years, *SD* = 3.0 years) with a mean laterality quotient of 94 (*SD* = 12) took part.

5.1.2. Material, Apparatus and Procedure

Visual stimuli consisted of one or two black boxes (width: 2 cm, height: 9 cm, located 5.3 cm to the left and/or to the right of the center of the screen, Index of difficulty according to Fitts, 1954: 2.7). If two boxes were presented, no black line indicated the approximate movement length before trials. Reversal movements were executed at five different tempi: 500 ms (2 Hz), 750 ms (1.3 Hz), 1000 ms (1 Hz), 1250 ms (0.8 Hz), and 1500 ms (0.6 Hz) for a complete reversal.

Each tempo in each condition was conducted twice and was always presented in the same order starting with the slowest tempo, proceeding to the fastest tempo, and then becoming slower again. Before each condition one trial at tempo 1000 ms was presented as a training trial. Within each experimental block conditions were presented in random order and the order of the two experimental blocks was counterbalanced across participants. The experiment took approximately 90 minutes.

5.1.3. Data Analysis

3% to 5% of movements in each condition were excluded from data analysis. As we had no specific hypothesis about differences between the two experimental blocks they were analyzed separately. Data were analyzed using repeated measurement ANOVAs with the factors GoalCondition (target, effect), GoalCombination (combined, single) and Tempo (1500 ms, 1250 ms, 1000 ms, 750 ms, 500 ms). RMT and MA were subjected to 2 x 3 factors repeated measurement ANOVAS with the factors GoalCondition (target, effect) and Tempo (1500 ms, 1250 ms, 1000 ms, 750 ms, 500 ms).

5.2. Two spatial targets/one temporal goal block: Results

5.2.1. Shape of Trajectory

Proportional time to peak velocity (PTPV, see Figure 2.5, Panel A). There were significant main effects of GoalCondition, $F(1, 23) = 10.45$, $MSE = 33.44$, $p = .004$, indicating that PTPV was higher in target than in effect conditions, and Tempo, $F(4, 92) = 115.78$, $MSE = 33.12$, $p < .001$ ($\varepsilon = 0.42$), indicating that PTPV increased with tempo (all $p < .001$). The main effect of GoalCombination, $F(1, 23) = 8.5$, $MSE = 142.24$, $p = .008$, indicated that PTPV was higher in movements towards the combined than towards the single goal. This was modified by a significant GoalCondition x GoalCombination x Tempo interaction, $F(4, 92) = 2.89$, $MSE = 4.89$, $p = .027$, reflecting that differences between movements towards combined and single goals at 1500 ms and 1250 ms tempo in the target condition, $t(23) = 1.09$, $p = .285$ and $t(23) = 1.71$, $p = .101$, and at the 500 ms tempo in the effect condition did not reach significance, $t(23) = 1.98$, $p = .06$.

Proportional movement time (PMT, see Figure 2.5, Panel B). A significant GoalCondition x GoalCombination interaction, $F(1, 23) = 6.8$, $MSE = 2.78$, $p = .016$, shows that in the target condition movements towards combined goals have a lower PMT than movements towards the single goal, $t(23) = 2.69$, $p = .013$, while in the effect condition overall movements towards combined goals and the single goal do not differ significantly, $t(23) = 0.93$, $p = 0.362$. The GoalCombination x Tempo interaction, $F(4, 92) = 5.27$, $MSE = 1.97$, $p < .001$ ($\varepsilon = .66$), reveals that in all tempi except the 750 ms, $t(23) = 1.98$, $p = .06$, and 500 ms, $t(23) = 0.06$, $p = .952$, tempi movements towards the combined goal have a lower PMT than movements towards the single goal (1500 ms, 1250 ms and 1000 ms: all $t(23) > 2.58$, all $p < .002$). However, the three-way interaction was not significant, $F(4, 92) = 1.42$, $MSE = 1.00$, $p = .235$.

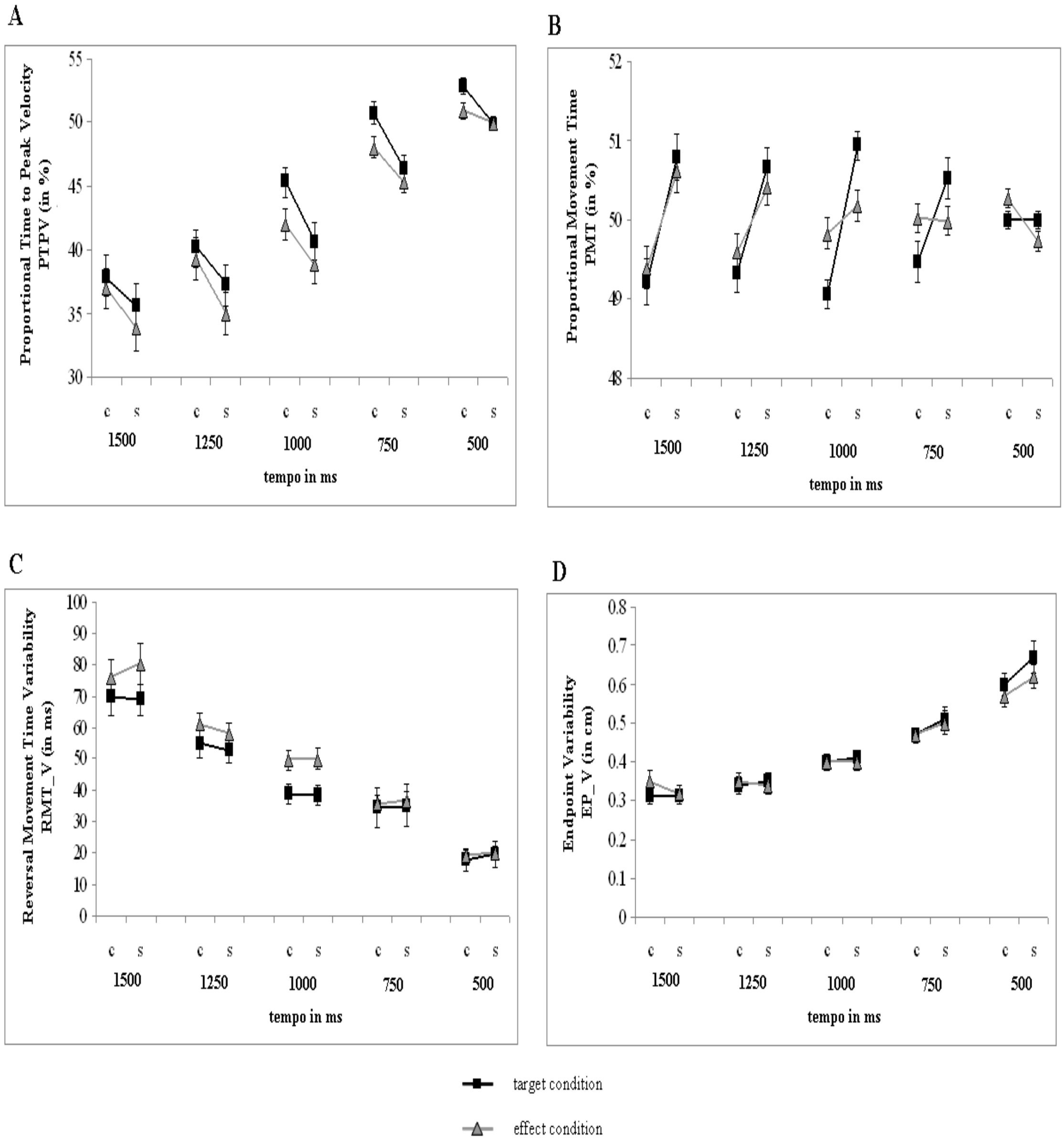

Figure 2.5. Experiment 3, two spatial targets/one temporal goal block (c = combined goal, s = single goal): Means and standard errors (error bars represent +/- 1 SE) of proportional time to peak velocity in % (PTPV, Panel A), proportional movement time in % (PMT, Panel B), Reversal Movement Time Variability in ms (RMT_V, Panel C) and Endpoint Variability in cm (EP_V, Panel C).

5.2.2. Temporal performance

Reversal movement time variability (RMT_V, see Figure 2.5, Panel C). There was a main effect of Tempo, $F(4, 92) = 63.74$, $MSE = 638.65$, $p < .001$ ($\varepsilon = 0.61$), showing that temporal variability decreases significantly with increasing tempo (all $p < .001$, except for the transition from tempo 1000 ms to 750 ms, $p = .318$). There were no significant main effects or interactions with the factor GoalCondition, indicating that target and effect conditions did not differ in RMT_V.

Reversal movement time (RMT). No significant main effect of or interactions with the factor GoalCondition were observed.

Pearson correlations of RMT_V. All correlations of RMT_V between target- and effect directed movements were positive (except for one), but none of them was significant (range: $r = -.004$ to $r = .328$).

5.2.3. Spatial performance

Endpoint variability (EP_V, see Figure 2.5, Panel D). Differences between conditions were only observed at the 500 ms tempo. The significant GoalCombination x Tempo interaction, $F(4, 92) = 7.7$, $MSE = 0.03$, $p < .001$ ($\varepsilon = 0.77$), reflects that at the 500 ms tempo movements towards the single goal had a significantly higher EP_V than movements towards the combined goal, $t(23) = 3.74$, $p < .001$. The GoalCondition x Tempo interaction, $F(4, 92) = 2.75$, $MSE = 0.004$, $p = .033$ ($\varepsilon = 0.7$), shows that target conditions have a higher EP_V ($M = 0.64$ cm) than effect conditions ($M = 0.59$ cm) at 500 ms tempo, $t(23) = 2.4$, $p = .025$.

Movement amplitude on the x axis (MA). Means ranged from 10.7 to 10.9 (M = 10.8, SE = 0.004), indicating that participants moved approximately the instructed MA (10.6 cm). There were no significant main effects or interactions.

5.3. Two spatial targets/one temporal goal block: Discussion

In general, participants showed temporal kinematics towards the combined goal (higher PTPV, lower PMT at slower tempi). Only small differences between target and effect conditions were observed in the shape of trajectory, reflecting a more pronounced temporal kinematic pattern in target conditions (higher PTPV, more pronounced differences in PMT). Correlations of RMT_V were low and not significant. The effect condition had lower EP_V than the target condition at the fastest tempo.

Overall a temporal kinematic pattern in the shape of the trajectory is observed in both goal conditions at all tempi, except the fastest tempi. Thus, in contrast to what we expected according to the results of Rieger (2007) there was no clear evidence for a spatial movement pattern in slower tempi. An explanation could be that the spatial targets had a lower index of difficulty (2.7) than the spatial targets in Rieger (2007, index of difficulty = 4.7). In the present experiment, spatial targets are effortlessly taken into account at slower tempi (no differences in EP_V between goal combinations at slower tempi). Only at the fastest tempo, movements towards the combined goal show some spatial aspects (e.g. in PMT) and correspondingly also lower EP_V than movements towards the single goal (spatial target). The observation that participants are more concerned with meeting the spatial demands at the combined goal than at the single spatial target at the 500 ms tempo is in accordance with the assumption that the representation of goals (i.e. the combined goal as the major goal) rather than the physical characteristics of the goals determine movement characteristics (Rieger, 2007).

There were only small differences between target and effect conditions depending on tempo. The temporal kinematic pattern is less pronounced in the effect than in the target conditions, especially at the 500 ms tempo. Correspondingly, EP_V is lower in the effect than in the target condition at this tempo. Does this mean that participants are better able to incorporate spatial aspects of the task in the effect conditions? Because effect conditions allow for higher temporal variability, this may be the case. However, the results can also be interpreted as a reduced temporal kinematic pattern. Empirically we cannot distinguish between the two possibilities in the present experiment. However, the latter interpretation is consistent with the results from Experiments 1 and 2.

In contrast to the previous experiments correlations of RMT_V in effect and target conditions, though positive, did not reach significance. This is not only a power problem, because correlations were numerically lower than in the previous experiments. It could be that participants differ in their strategies of how they integrate temporal and spatial requirements of the task in target and effect conditions. As a consequence the spatial aspects of the task may lead to dissimilar timing mechanisms in target and effect conditions.

5.4. One spatial target/two temporal goals block: Results

5.4.1. Shape of Trajectory

Proportional time to peak velocity (PTPV, see Figure 2.6, Panel A). The main effects of GoalCondition, $F(1, 23) = 43.63$, $MSE = 22.06$, $p < .001$, GoalCombination, $F(1, 23) = 47.81$, $MSE = 35.38$, $p < .001$, and Tempo, $F(4, 92) = 76.2$, $MSE = 49.52$, $p < .001$ ($\varepsilon = 0.33$), show that movements in target conditions, movements towards single goals, and movements at faster tempi (all $p < .001$) have a higher PTPV. Further, the GoalCondition x Tempo interaction, $F(4, 92) = 5.04$, $MSE = 5.98$, $p = .004$ ($\varepsilon = 0.7$), reveals that while in all other tempi PTPV increases significantly, this is not the case in target conditions from tempo 750 ms to 500 ms, $t(23) = 0.9$, $p = .376$. The GoalCombination x Tempo interaction, $F(4, 92) = 7.47$, $MSE = 4.93$, $p < .001$ ($\varepsilon = 0.52$), shows that differences between movements towards combined goals and single goals are higher in slow than in fast tempi.

Proportional movement time (PMT, see Figure 2.6, Panel B). There was only a significant GoalCombination x Tempo interaction, $F(4, 92) = 10.94$, $MSE = 1.08$, $p < .001$ ($\varepsilon = 0{,}51$), which shows that at tempo 1500 ms, $t(23) = 2.95$, $p = .007$, and 1250 ms, $t(23) = 2.34$, $p = .028$, movements towards the combined goal have a higher PMT than movements towards the single goal, while this pattern reverses at tempo 750 ms and 500 ms. Here movements towards the single goal have a higher PMT (750 ms: $t(23) = 1.84$, $p = .04$; 500 ms: $t(23) = 3.59$, $p = .002$).

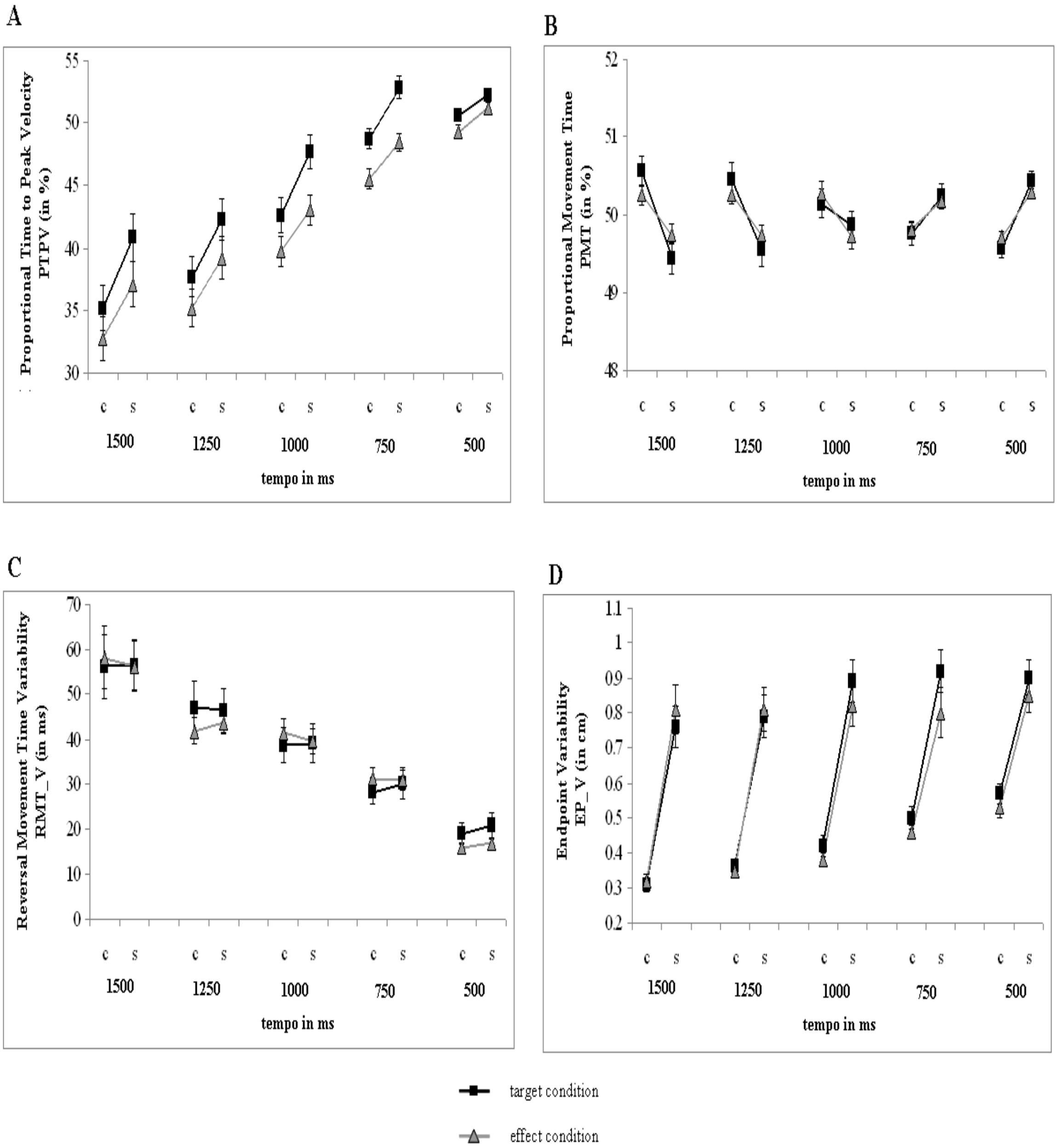

Figure 2.6. Experiment 3, one spatial target/two temporal goals block (c = combined goal, s = single goal): Means and standard errors (error bars represent +/- 1 SE) of proportional time to peak velocity in % (PTPV, Panel A), proportional movement time in % (PMT, Panel B), Reversal Movement Time Variability in ms (RMT_V, Panle C) and Endpoint Variability in cm (EP_V, Panel D).

Temporal performance

Reversal movement time variability (RMT_V, see Figure 2.6, Panel C). There was only a main effect of Tempo, $F(4, 92) = 50.82$, $MSE = 387.75$, $p < .001$ ($\varepsilon = 0.41$), showing that temporal variability decreases with increasing tempo (all $p < .01$).

Reversal movement time. (RMT). A significant main effect of GoalCondition, $F(4, 92) = 4.52$, $MSE = 17229.9$, $p = .044$, indicates that RMT is higher in effect conditions (M = 1005 ms, *SE* = 14 ms) than in target conditions (M = 969 ms, *SE* = 6 ms).

Pearson correlations of RMT_V). Correlations of temporal variability between target- and effect-directed movements were positive, except at the fastest tempo (range: r = -.171 to $r = .537$. However, only two coefficients reached significance.

5.4.2. Spatial performance

Endpoint variability (EP_V, see Figure 2.6, Panel C). A significant main effect of GoalCombination, $F(1, 23) = 164.59$, $MSE = 0.1$, $p < .001$, indicated that movements towards the single goal have higher EP_V ($M = 0.8$ cm) than movements towards the combined goal ($M = 0.4$ cm). The GoalCombination x Tempo interaction, $F(4, 92) = 4.55$, $MSE = 0.2$, $p = .002$, shows that EP_V increases with increasing tempo in movements towards the combined goal (all $t(23) > 3.13$, all $p < .01$). This is not the case in movements towards the single goal. The GoalCondition x Tempo interaction, $F(4, 92) = 2.5$, $MSE = 0.2$, $p = .022$, reflects that target conditions have a higher EP_V than effect conditions at 750 ms tempo.

Movement amplitude on the x axis (MA). Mean MA values ranged from 10.3 cm to 11.2 cm (M = 10.7, SE = 0.008), indicating that participants approximated the instructed movement length. A significant main effect of GoalCondition, $F(1, 23)$ = 16.64, MSE = 1.07, $p < .001$, shows that MAs in effect conditions are shorter (M = 10.5 cm) than in target conditions (M = 11 cm).

5.5. One spatial target/two temporal goals block: Discussion

In sum, apart from a lower PTPV in the effect than in the target condition, trajectories are equally shaped. There was a clear transition from spatial kinematics (relatively high PMT) to temporal kinematics (relatively low PMT) towards the combined goal at faster tempi (beginning from tempo 750 ms). This transition was not observed in PTPV. However, in PTPV the difference between single and combined goals decreased at faster tempi. Correlations of RMT_V tended to be positive, but failed to reach significance in most cases. EP_V was higher at the single than at the combined goal side. Further, at combined goals EP_V increased at faster tempi. This shows that it becomes increasingly difficult to meet both temporal and spatial goals as tempo increases. In effect conditions participants show higher RMT and shorter MA than in target conditions, which may reflect higher task difficulty of effect conditions (similar to Experiment 1, same goals set).

As expected, movement patterns change from spatial kinematics at 1500 ms, 1250 ms and 1000 ms tempo to temporal kinematics at 750 ms and 500 ms tempo (PMT, some indication for this was also observable in PTPV). Temporal goals are less demanding at slower tempi, therefore participants can incorporate the spatial characteristics of the combined goal into the movement pattern. At faster tempi temporal goals become more demanding, and they take precedence in shaping the movement towards the combined goal (i.e. the major goal, cf. Rieger, 2007).

In contrast to our hypothesis there are only small differences between target- and effect-directed movements in the overall kinematic pattern. PTPV was lower in effect than in target conditions, indicating a less pronounced temporal kinematic pattern.

However, that change in the kinematic pattern towards the combined goal from spatial to temporal occurred at the same tempo in target and in effect conditions.

Correlations of RMT_V are not high. Again, participants may differ in their strategies of how they integrate temporal and spatial aspects of the task in target and effect conditions, leading to dissimilar timing mechanisms.

In summary results of Experiment 3 indicate that target- and effect-directed movements are influenced by tempo demands and additional targets in a similar way. Only gradual differences between target- and effect-directed movements were observed.

6. General Discussion

The present study was conducted to investigate whether movement execution – that is *how* a movement is performed- follows similar principles in movements towards targets and effects. We assumed that this may be the case because targets and effects are both action goals and should therefore be represented in a similar way. However, differences between targets and effects, concerning the precision of temporal information and required information processing demands, may also lead to differences in movement execution. To the best of our knowledge a direct comparison of target-directed and effect-directed movements under comparable conditions has not been conducted before. We therefore investigated movements towards auditory-temporal targets and auditory-temporal effects in three experiments.

In summary in all three experiments movement kinematics towards temporal targets and temporal effects were very similar, indicating that essentially target- and effect-directed movements are governed by the same principles. Both target- and effect-directed movements show a temporal kinematic pattern (late peak velocity, relatively short movement time) when moving towards a temporal goal. Similar kinematic patterns in target- and effect-directed movements were observed in a variety of experimental manipulations: In both goal conditions an irrelevant goal characteristic (i.e. loudness, Experiment 1) was integrated in the goal representation. When targets and effects were presented within the same reversal movement, similarities between them were enhanced rather than reduced (Experiment 2), and even when the task posed spatial demands in addition to temporal demands (Experiment 3), target- and effect-directed movements were performed in a very similar way. Correlations between temporal variability of target- and effect-directed movements showed that they have a common source of temporal variability (Experiments 1 and 2). Individual differences are therefore not specific for the type of goal (cf. Zelzanik et al., 2002; Zelzanik et al., 2005; Vardy et al., 2009). This was however not the case when spatial in addition to temporal requirements had to be taken into account (Experiment 3). In this case, participants may differ in their strategies how they integrate temporal and spatial aspects of the task in target and effect conditions, leading to less similar timing mechanisms.

Some differences between target and effect-directed movements were also observed. Apart from Experiment 2, proportional time to peak velocity was always lower in effect-directed than in target-directed movements. Effect-directed movements sometimes also show higher temporal variability (Experiment 1 and Experiment 2, though this effect was not unequivocally interpretable in Experiment 1). Further, when both temporal and spatial restrictions were present, the differences between the kinematic patterns to different goals were less pronounced in effect than in target conditions (Experiment 3, two spatial targets/one temporal goal block).

We assume that more accurate timing in target-directed than in effect-directed movements stems from the inherent characteristics of the respective goals. Targets provide more precise temporal information for movement execution, are not influenced by the variability of the self-produced temporal structure, and they occur regardless of whether a person is acting or not. A more imprecise temporal representation in effect conditions may in turn result in a less pronounced temporal kinematic pattern than in target-directed actions (lower proportional time to peak velocity, Experiment 1 and 3); maybe also related to higher processing demands in effect-directed actions.

Because the observed differences between effect-directed and target-directed movements were only differences in the degree of a kinematic pattern, but not differences in the patterns themselves, we so far argued that only quantitative, but not qualitative differences between targets and effects exist. An alternative interpretation is that rather than quantitative, differences between target- and effect directed movements are qualitative. Participants may apply additional cognitive processes or strategies in effect conditions in comparison to target conditions in order to compensate for the imprecision of the temporal goal. Specifically, rather viewing the kinematic pattern as being 'temporally less pronounced' in effect conditions, one may also argue that it is 'more spatial'. Participants may encode the spatial dimensions of their movements (even though no spatial goals were present in Experiment 1 and 2, movements still have to occur in space) to a stronger degree in effect-directed than in target-directed actions. For example, participants may rely on a representation of a certain movement amplitude or encode spatial endpoints of the movements as an auxiliary strategy to aid them performing in rhythm. However, there is no a priori reason why this should occur in effect- but not in target-directed actions as both have the same (implicit) spatial components. Further, in both conditions participants were presented with a prototype amplitude, which they approximated equally well in effect- and target-directed actions. Small differences in amplitudes which were observed between conditions were probably related to the respective difficulty of the conditions, with more difficult conditions resulting in shorter amplitudes. Additionally, such spatial strategies should result in lower endpoint variability. However, no systematic differences between effect-directed and target-directed movements in endpoint variability were observed.

Even if there are some differences in the processes of target and effect-directed actions, the observed similarities between target-directed and effect-directed movements nevertheless provide evidence for the assumption that both auditory-temporal targets and auditory-temporal effects function as goals of actions. In both cases movement kinematics are shaped by the goal representation preceding the movement in a way that is typical for temporal constraint movements in order to optimally achieve timing goals (e.g. Ivry et al., 2004; Rieger, 2007). The influence of upcoming events on movement execution is in accordance with the ideomotor principles of action control, according to which the anticipation of the intended consequences of a movement guides not only movement selection (Knuf, Aschersleben, & Prinz, 2001), and initiation (Kunde, 2003), but also movement execution (Kunde et al., 2004). The goal of a target-directed movement is to be somewhere at a given time (Rieger, 2007), whereas the goal of an effect-directed movement is the production of the effect itself. Goal representation in combination with the ideomotor principle of action control can also provide an explanation for the kinematics found in other studies investigating target-directed and effect-directed movements in other domains (Billon et al., 1996; Dahl, 2000; Balasubramaniamet al., 2004; Doumas & Wing, 2007; Torre & Balasubramaniam 2009; Repp & Steinmann, 2010).

Theories of ideomotor control distinguish between proximal (related to the body) and distal (related to the environment) action effects (Hoffmann et al., 2007; Prinz, 1987). According to this distinction, action effects in our experiments may be regarded as distal action effects (comparable to a piano tone), whereas action targets in our experiments evoke proximal action effects (related to the bodily sensations at the occurrence of the temporal target, comparable to tactile sensations when pressing a piano key). It is sometimes assumed that ideomotor control of actions is predominantly governed by distal action effects (e.g. Prinz, 1992; Hommel, Müsseler, Aschersleben, & Prinz, 2001). If this assumption is applied to our task, one would expect more pronounced temporal kinematics in the effect condition than in the target condition. This was however not the case. We argue that action targets themselves are equal to action effects and evoke the same kind of representations (in the context of our experiments: auditory-temporal event anticipations) and may therefore reside on the same level of "distality". So far action targets are neglected in ideomotor theories, apart from the assumption that proximal effects are produced at action targets. However, as our study shows, targets and effects may serve equally as actions goals. Ideomotor theories should thus be expanded to cover goal-based (including target- and effect-based), rather than only effect-based action control.

One may be tempted to compare effect-directed and target-directed actions to intention-based (that is internally generated) and stimulus-based (that is externally generated) actions. Internally generated actions require greater levels of preparation than externally generated actions, and they may be processed in different ways by the motor system (Obhi & Haggard, 2004). Such differences may also apply to target-directed and effect-directed actions. Indeed, we argued that effect-directed actions may require higher processing demands than target-directed actions. Similarly, in the context of ideomotor theories it has been discussed that the occurrence of ideomotor learning may depend on whether intention-based or stimulus-based learning is required by the task (Waszak et al., 2005, but see Elsner & Hommel, 2004; Ziessler &

Nattkemper, 2002; Wenke, Waszak, & Haggard, 2009), though other factors such as the complexity of the studied action (Herwig & Waszak, 2009), or whether intentional action selection or intentional action timing takes place (Krieghoff, Brass, Prinz, & Waszak, 2009) may also influence ideomotor learning. However, the comparison of effect- and target-directed actions to intention- and stimulus-based actions does not hold. Target-directed actions and stimulus-based actions differ because the action usually *follows* the stimulus in stimulus-based actions, and learning of subsequent effects is incidental. In contrast, in target-directed actions the action is produced in order to coincide with a future event and thus the action of interest *precedes* the stimulus. Therefore target-directed actions cannot be equated with stimulus-based (i.e. externally generated) actions. In order to represent temporal targets as goals of an action, it is however necessary that the time at which a temporal target will be presented is predictable, as it is the case in isochronous rhythms.

To conclude, the presented findings are in favor of the assumption that movement control relies heavily on goal representations. Only gradual differences between target and effect-directed movements were observed. Both targets and effects can function as action goals (here: auditory-temporal goals), as the kinematic patterns towards both reflect the anticipation of upcoming events. Movements towards both goals are similarly influenced by a variety of different factors (i.e. loudness of the goal, speed, additional task requirements). Ideomotor theories of action control should incorporate action targets as action goals similar to action effects.

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Supplementary Material

Table 2.2. Supplementary Material. Experiment 1: Control variables. Means and standard errors (in parenthesis) of reversal movement time (RMT) and movement amplitude on the x-axis (MA).

	1250 ms tempo			750 ms tempo		
	One goal	Same goals	Different goals	One goal	Same goals	Different goals
	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)
Reversal movement time in ms (RMT)						
target-directed	1242 (6)	1247 (3)	1241 (6)	755 (1)	746 (8)	758 (1)
effect-directed	1240 (27)	1244 (26)	1210 (18)	816 (14)	788 (14)	787 (9)
Movement amplitude on the x-axis in cm (MA)						
target-directed	10.9 (0.06)	11.4 (0.06)	11.0 (0.06)	10.2 (0.05)	11.6 (0.06)	11.5 (0.05)
effect-directed	11.2 (0.05)	11.1 (0.06)	10.7 (0.06)	10.3 (0.04)	10.4 (0.05)	10.4 (0.05)

Table 2.3. Supplementary Material. Experiment 2: Control variables. Means and standard errors (in parenthesis) of reversal movement time (RMT) and movement amplitude on the x-axis (MA).

	Same-goals: target-directed	Same goals: effect-directed	Different goals
	M (SD)	M (SD)	M (SD)
Reversal movement time in ms (RMT)			
1250 ms	1248 (10)	1236 (17)	1220 (17)
1000 ms	1007 (6)	1012 (6)	990 (6)
750 ms	755 (4)	756 (5)	751 (5)
Movement amplitude on the x-axis in cm (MA)			
1250 ms	10.7 (0.5)	10.8 (0.6)	10.3 (0.4)
1000 ms	11.2 (0.5)	10.9 (0.6)	10.1 (0.6)
750 ms	11.0 (0.5)	10.1 (0.5)	9.9 (0.5)

Table 2.4. Supplementary Material. Experiment 2: Pearson correlation coefficients of temporal variability (RMT_V). On the left side correlations of target-directed movements of the same goals set with target-directed and effect-directed movements of the different goals set can be seen. On the right side correlations of effect-directed movements of the same goals set with target-directed and effect-directed movements of the different goals set are depicted. Values are shown separately for each tempo (750 ms, 1000 ms, and 1250 ms).

	Same goals: target-directed movements		Same goals: effect-directed movements	
	Different goals: target-directed	Different goals: effect-directed	Different goals: target-directed	Different goals: effect-directed
1250 ms	.615**	.670**	.715**	.686**
1000 ms	.576**	.637**	.535**	.567**
750 ms	.349	.461*	.221	.239

*Note: * p < .05; ** p < .01*

Table 2.5. Supplementary Material. Experiment 3: Control variables. Two spatial targets/one temporal goal block in the upper part and one spatial target/two temporal goals block in the lower part. Means and standard errors (in parenthesis) of reversal movement time (RMT) and movement amplitude on the x-axis (MA).

	1500 ms tempo M (SD)	1250 ms tempo M (SD)	1000 ms tempo M (SD)	750 ms tempo M (SD)	500 ms tempo M (SD)
two spatial targets/one temporal goal block					
Reversal movement time in ms (RMT)					
target-directed	1479 (6)	1238 (4)	995 (2)	752 (7)	507 (10)
effect-directed	1466 (33)	1252 (20)	1017 (12)	770 (13)	518 (7)
Movement amplitude on the x-axis in cm (MA)					
target-directed	10.7 (0.1)	10.7 (0.0)	10.8 (0.1)	10.9 (0.1)	10.9 (0.1)
effect-directed	10.7 (0.1)	10.7 (0.1)	10.7 (0.1)	10.7 (0.1)	10.7 (0.2)
one spatial target/two temporal goals block					
Reversal movement time in ms (RMT)					
target-directed	1470 (21)	1213 (17)	967 (15)	713 (13)	481 (9)
effect-directed	1480 (14)	1243 (8)	1016 (9)	770 (9)	514 (7)
Movement amplitude on the x-axis in cm (MA)					
target-directed	10.8 (0.3)	10.9 (0.3)	11.2 (0.3)	11.2 (0.2)	10.9 (0.3)
effect-directed	10.6 (0.3)	10.4 (0.3)	10.5 (0.3)	10.5 (0.3)	10.3 (0.4)

Table 2.6. Supplementary Material. Experiment 3: Correlations of temporal variability between target-directed and effect-directed movements. Pearson correlation coefficients are depicted for every block and towards both GoalCombinations at each tempo.

	Two spatial targets/one temporal goal block		One spatial target/two temporal goals block	
	Combined goal	Single goal	Combined goal	Single goal
1500 ms	.328	.296	.177	.248
1250 ms	.241	.314	.244	.257
1000 ms	.250	.274	.378	.454*
750 ms	.090	.063	.537**	.356
500 ms	-.004	081	-.171	-.001

*Note: * p < .05; ** p < .01*

Chapter 3

Similar mechanisms of movement control in target- and effect-directed actions towards spatial goals?

Shortened Title: Spatial targets and effects

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Frontiers in Psychology, 2012, 3:539.

Abstract

Previous research has shown that actions conducted towards temporal targets and temporal effects are controlled in a similar way. To investigate whether these findings also apply to spatially restricted movements we analyzed movement kinematics of continuous-reversal movements towards given spatial targets and towards self-produced spatial effects in two experiments. In Experiment 1 target- and effect-directed movements were investigated in three different goal constellations. A spatial target/effect was always presented/produced on one movement side, on the other side either a) no target/effect, b) the same target/effect, or c) a more difficult target/effect was presented/produced. Results showed that both target-directed and effect-directed movements have a typical spatial kinematic pattern and that both can be equally well described by linear functions as suggested by Fitts´ Law. However, effect-directed movements have longer movement times. In Experiment 2 participants performed target-directed movements to the one side and effect-directed movements to the other side of a reversal movement. More pronounced spatial kinematics were observed in effect-directed than in target-directed movements. Together, the results suggest that actions conducted towards spatial targets and spatial effects are controlled in a similar manner. Gradual differences in the kinematic patterns may arise because effects are cognitively more demanding. They may therefore be represented less accurately than targets. However, there was no indication of qualitative differences in the cognitive representations of effects and targets. This strengthens our assumption that both targets and effects play a comparable role in action control: they can both be viewed as goals of an action. Thus, ideomotor theories of action control should incorporate action targets as goals similar to action effects.

1. Introduction

Every day we perform intentional, goal-directed actions. Action goals differentiate an action from pure movement and fall into two broad categories. The goal of an action can either consist of generating a change in the environment (i.e. to produce an effect, for example turning on a switch in order to illuminate a dark room) or of changing one's own situation in the environment (i.e. to move to a physical target, for example reaching out in order to grasp a cup). In the following we refer to these different types of goal-directed actions as effect-directed and target-directed actions, respectively.

Action goals have been known to play an important role in movement organisation for a long time. In the present paper action goals are viewed in the light of the ideomotor theory of action control (James, 1890/1981; Prinz, 1997). The ideomotor theory has found broad empirical evidence (Elsner & Hommel, 2001, 2004; Hommel, Alonso, & Fuentes, 2003; for a historical overview see Stock & Stock, 2004) and states that an action is selected, initiated, and executed by anticipating the perceptual consequences of the action in question. Here we assume that both targets and effects are represented as action goals in motor control in the sense of the ideomotor theory. The representation of the intended perceptual consequences, in both target- and effect-directed movements, is responsible for the initiation, selection, and execution of a movement. In effect-directed actions the goal is the production of the effect and the manipulation of the environment itself. Target-directed actions also entail the representation of action goals such as "to be at a certain place at a given time".

However, so far studies investigating predictions derived from ideomotor theory have mainly been concerned with the role of action effects. If action targets are considered at all, they are usually not treated as major goals of an action but as subgoals. For example, action targets are sometimes defined as the location at which an event has to occur (e.g. participants perform a key-press in a certain location) before an effect occurs (e.g. an effect tone; Hoffmann, Lenhard, Sebald & Pfister, 2009). In this kind of situation targets and effects are related, and effects are higher in the goal hierarchy. In other terms, according to ideomotor theories, which distinguish between proximal (related more closely to the body) and distal (related to the environment) action effects (Hoffmann et al., 2007; Prinz, 1987), effects are more distal than targets in such experiments. Such a scenario applies of course to many everyday situations but not to all. As outlined above, it is not always the goal of an action to produce a change in the environment (to produce an effect), but it is also sometimes the goal to change one's own situation in the environment (e.g. to move to a target). In the present study, we treated targets and effects as two different types of goals, which may be hierarchically equal and independent from each other. Thus, we designed the experiments in a way that the cognitive representations of targets and effects reside on the same level of "distality". Participants moved to visuo-spatial targets and moved to produce visuo-spatial effects. In both instances, participants received the same proximal effects (i.e. proprioception, kinesthesis), but the distal goal representations differed. With effects, the distal goal representation consisted of the occurrence of the effect, whereas with targets the distal goal representation consisted of being in a certain position. Still, as both goal representations are major action goals, they should have a similar influence on movement execution.

Thus, the major goal of the present study was to investigate the commonalities and differences between target-directed and effect-directed actions and their underlying mechanisms of action control. Recently, we have shown that the same mechanisms of action control underlie movements directed towards auditory-temporal targets and auditors-temporal effects (Walter & Rieger, 2012). Walter & Rieger (2012) showed that typical temporal movement kinematics emerged when participants synchronized movements with regularly presented tones (target-directed movements) or produced tones themselves (effect-directed movements). We concluded that both targets and effects can be seen as goals of an action influencing movement execution by the anticipation of upcoming events. This study however only investigated auditory-temporal stimuli as action goals. In the present study, we wanted to investigate whether our previous conclusions extent to visual-spatial action goals. This is not self-evident, because differences in the way spatially and temporally restricted movements are controlled are observed in some studies (e.g. Franz, Eliassen, Ivry, & Gazzaniga, 1993; Heuer, 1993; Maslovat, Hodges, Chua & Franks, 2011).

The role of visual spatial targets for movement planning and initiation has been demonstrated. For example, people bring their hand in a position that may be uncomfortable at the beginning of a grasping movement but that will allow them to be in a comfortable posture that facilitates optimal control at the end of the movement (known as the end-state comfort effect, for a review see Rosenbaum, Chapman, Weigelt, Weiss, & van der Wel, 2012). Further, if participants have initial information about a second target in a two-step movement sequence, but no information about the first target before the beginning of the sequence, movements are initialized faster than when they have no information about both targets in the sequence (Herbort & Butz, 2009). This finding is consistent with models of anticipatory movement planning that claim that in a movement sequence each step is planned in reverse order (Fischer, Rosenbau, & Vaughan, 1997) and confirms the assumption that upcoming targets are processed and movement execution towards them can be partially planned, resulting in faster movement initiation.

A wide variety of studies investigated the role of visual-spatial targets for movement execution. Over a century ago Woodworth described that it is impossible to be fast and accurate at the same time when moving towards a visual target (Woodworth, 1899). This limitation of the motor system known as speed-accuracy tradeoff has been mathematically described by Fitts´ (Fitts, 1954; Fitts & Peterson, 1964) showing that movement time increases linearly with task difficulty. Fitts specified task difficulty (index of difficulty: ID) as a function of target width and target distance (for a review and different ways to calculate ID see Plamondon & Alimi, 1997). This relation is widely known as Fitts´ Law and has inspired scientific research until today, especially in the field of human computer interface studies. Fitts´ Law holds for bimanual tasks as well as tasks performed by dyads (Mottet, Guiard, Ferrand, & Bootsma, 2001). Further, Fitts´ Law can be applied for translational as well as rotational movements (Stoelen & Akin, 2010) and has been studied intensively for distant aiming tasks with computer devices (Kopper, Bowman, Silva & McMahan, 2010). Whereas most studies investigated pointing and aiming with discrete tasks (for a review see Elliott, Helsen, Carson, Goodman, & Chua, 1991), in some studies continuous tasks were used (e.g. Motett et al, 2001). The kinematics of movements aimed at spatial targets frequently show asymmetric velocity profiles (Elliott, Helsen, & Chua, 2001). Specifically, movements towards spatial targets show a kinematic pattern that differs substantially from the kinematics of movements towards non-targets. Movements towards spatial targets reach peak velocity earlier and have relatively long movement times (Rieger, 2007). We will refer to this pattern as spatial movement kinematics in the following. Such spatial movement kinematics lead to prolonged time in the target area at the end of the movement. This additional time can be used to increase spatial accuracy (Rieger, 2007; Elliott et al, 2001; Novak, Miller & Houk, 2000).

Studies investigating the role of visual-spatial effects have mainly been conducted in the context of the ideomotor theory of action control (e.g. Kunde, Müsseler, & Heuer, 2007; Hommel, Müsseler, Aschersleben, & Prinz, 2001; Hommel, 1993). It has been shown that participants respond faster if an action produces an effect that is spatially compatible with their response (action-effect-compatibility, e.g. Kunde, 2001). Kunde (2001) showed that in compatible conditions (e.g. a left hand key press produces a light flash on the left side of the monitor) responses are initiated faster than in incompatible conditions (e.g. the left hand key press produces a light flash on the right side of the monitor). The role of action effects has also been investigated when participants use tools for generating visual spatial action effects. For example, when participants produce a rightward or leftward movement of a cursor on a display (that is a visual-spatial effect) by moving a steering wheel clockwise or counter-clockwise, movements are initiated faster when stimulus location (left-right tones) correspond to the direction of the produced effect (stimulus-effect-compatibility, Proctor, Wang, & Pick, 2004). Similarly, mental rotations facilitate manual rotations when the direction of the visual effect is compatible with the mental rotation (Janczyk, Pfister, Crognale, & Kunde, 2012). Whereas many studies investigated the role of visual-spatial effects for movement selection and initiation the question of their role for movement execution is rarely addressed. In other domains, it has however been shown that effect anticipation also affects action execution (Kunde, 2003; Kunde, Koch & Hoffmann, 2004).

To sum up, the existing literature on the role of visual-spatial targets and the role of visual-spatial action effects for movement control suggests that visual-spatial targets as well as visual-spatial effects may both serve as action goals in the sense of the ideomotor theory. To the best of our knowledge the role of visual-spatial targets and effects for action control has however not been systematically investigated in one study under comparable conditions when they reside on the same level of "distality". This is what we did in the present study.

Even though targets and effects may both serve as action goals, physical targets and effects also have some features that make them clearly distinguishable from each other. Targets are externally generated and usually present in the environment before, during and after the movement. Thus they can provide precise information for movement aiming and movement correction. In contrast, effects are only present in the environment after the movement has been executed (and often only for a limited amount of time) and their anticipatory representation relies solely on internal generation. As a consequence, memory and learning processes play a more prominent role in effect-directed than target-directed movements. Attention demands may also be higher in effect directed-movements than in target-directed movements, because in addition to other types of feedback the visual action effect has to be monitored in effect-directed actions. As a consequence, performing effect-directed in comparison to target-directed actions should be cognitively more demanding.

Thus, evidence suggests that movements towards spatial targets could be controlled in a similar way as movements towards spatial effects, as they are both goals of an action. Their different features could however also lead to differences in movement control. In the present study we wanted to investigate whether movements towards spatial targets and spatial effects are controlled in a similar way by comparing movements towards visual-spatial targets and movements towards self-produced visual-spatial effects. To this aim, we compared the kinematics of movements generating visual-spatial effects and the kinematics of movements towards visual-spatial targets. Participants performed continuous reversal movements on the medial-lateral axis. In target-directed movements they reversed their movement on constantly presented spatial targets, whereas in effect-directed movements they produced spatial stimuli themselves. We analyzed *how* target-directed and effect-directed movements are executed.

2. Experiment 1

Participants performed continuous reversal movements on the medial-lateral axis. They were asked to move continuously back and forth and reverse their movements within black boxes that were constantly present during an experimental trial (target conditions) or were asked to move constantly back and forth and to produce black boxes in the same position as in target conditions when they reverse their movements. We analyzed *how* target-directed and effect-directed movements are executed.

Targets and effects were presented in three different goal constellations (see Figure 3.1, left panel). On one side of the movement always the same standard box was presented/to be produced. On the other side either a) no box (one goal constellation), b) the same standard box (same goals constellation) or c) a different box with a higher Index of difficulty (different goals constellation) was presented/to be produced.

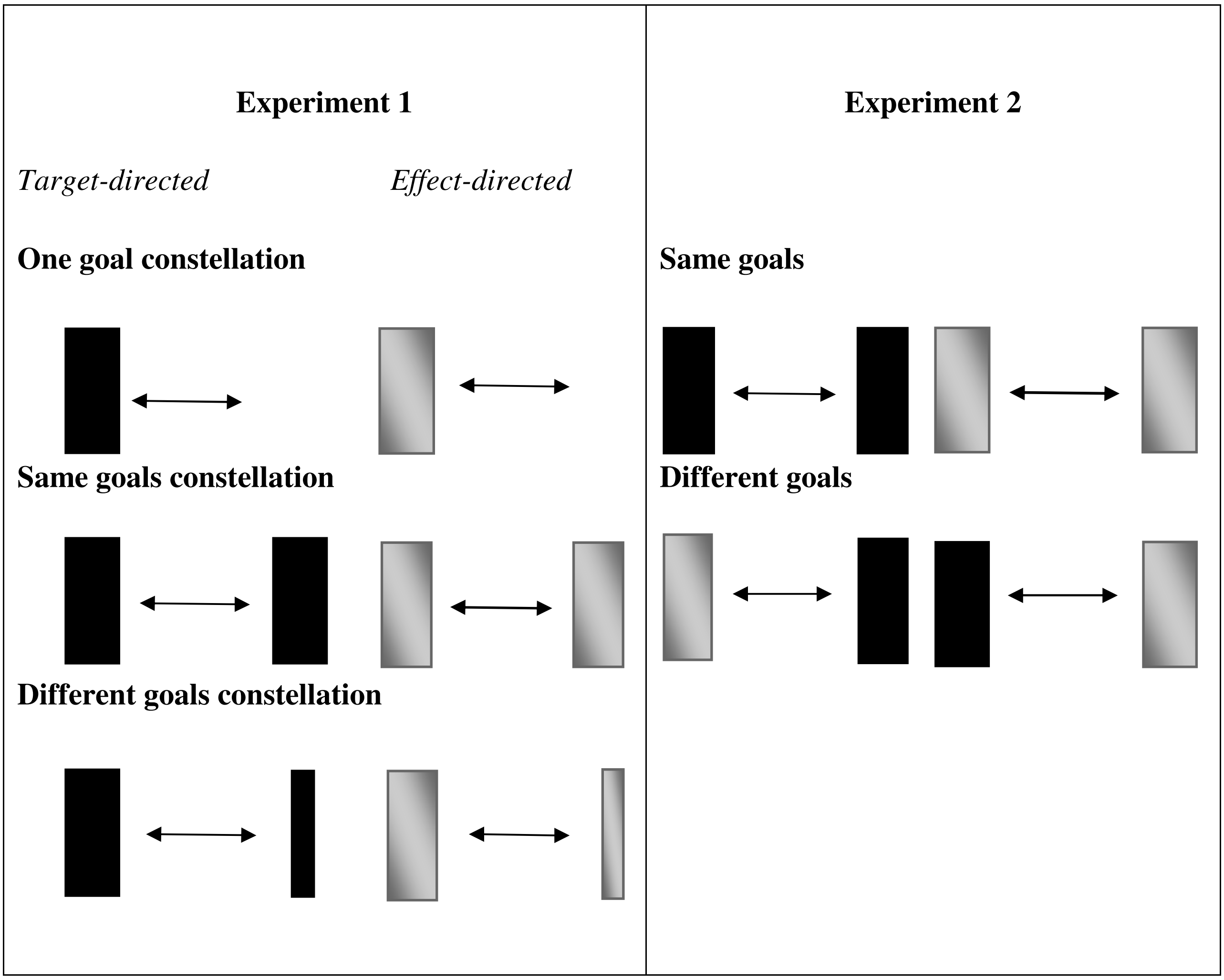

Figure 3.1. Graphical overview of the goal constellations in Experiment 1 and Experiment 2. Black boxes represent targets, grey boxes represent effects. Note that the color of targets as well as effects was black in the experiment. Wide boxes represent standard boxes (width: 2 cm, ID: 2.7), narrow boxes represent the more difficult boxes (width: 0.56 cm, ID: 4.3). In target-directed movements participants were asked to reverse their movements within constantly presented black boxes, while in effect-directed movements such boxes were self-produced as they only appeared whenever participants reached the x-position of the inner edge of the to-be-produced boxes.

We expected that in the one goal constellation both target- and effect-directed movements towards the standard box show spatial kinematic patterns (early peak velocity, relatively long movement times) compared to movements towards the no box side. No such differences should be observable in the same goals constellations. In different goals constellation target-directed movements towards the more difficult box (Fitts, 1954) should show more pronounced spatial movement kinematics compared to movements towards the standard box. As we assume that both targets and effects can be viewed as goals of an action we expected to observe similar movement kinematics in target and effect conditions. We expected that effect-directed movements have higher spatial variability since the exact position of the effect is only seen at the endpoint of the movement and thus has to be remembered, which is cognitively more demanding. Nevertheless, we expected that Fitts´ Law (Fitts, 1954) can equally well describe target and effect conditions. The comparison of target- and effect-directed movements across goal constellations is of particular interest in order to investigate how the goal representations in target and effect-directed movements are formed. Not only the presence/absence of a visual target is important for movement execution, but also its characteristics (i.e. target width). It is not clear, whether this will also be observed for self-produced visual effects. If only the presence/absence of a visual effect is represented but not its characteristics (width), movement kinematics in the same- and different goals constellation should not differ in the effect condition (but they should differ from the kinematics in the one-goal constellation). However, if the characteristics of the visual effect (width) are represented in effect conditions, movement kinematics in the same goals and different goals constellation should differ from each other, similar to what we expect in target conditions.

2.1. *Method*

2.1.1. Participants

20 healthy participants (10 female) took part in this experiment. All of them were right-handed according to Edinburgh Inventory (Oldfield, 1971) with a mean laterality quotient of 91 (*SD* = 15). Their mean age was 25.6 years (*SD* = 2.4 years). All of them reported normal or corrected-to-normal vision. They gave informed consent prior to the experiment and received 7 Euro for participation.

2.1.2. Materials and Apparatus

Movements were recorded with a 30.5 cm x 45.5 cm Wacom Ultrapad A3 writing pad at a resolution of 500 pixels per cm and at a rate of 172 Hz that was placed on a desk. Participants performed movements with their right (dominant) hand, which was shielded from view by a cover. Participants were able to see their movement trace consisting of a blue circle (4 mm in diameter) on a screen (17´´, resolution: 1024 x 768 pixels, vertical refresh rate: 100 Hz). Movement distance on the writing pad equaled movement distance on screen. The screen was placed behind the pad at a distance of 60 cm from the participants and 9 cm higher than the pad. Spatial stimuli consisted of black boxes (distance between the centers 10.6 cm, standard width: 2 cm, ID = 2.7, more difficult width: 0.56, ID = 4.3) presented 5.3 cm to left and/or the right of the middle of the screen. If only one box was present a black line of 10.6 cm length aligned horizontally in the middle of the screen indicated the approximate length of a movement in a demonstration phase. A red box (0.5 x 0.5 cm) presented in the middle of the screen served as a starting box. The software Presentation 14.1 was used for stimulus presentation and data recording.

2.1.3. Procedure

The experiment took place in a dimly lit room. Participants were asked to perform continuous reversal movements on the medial-lateral axis without pausing at the reversal points. Movements were performed in two different goal conditions: target condition and effect condition. When performing target-directed movements, participants were asked to reverse their movements within constantly presented black boxes. When performing effect-directed movements, participants were asked to produce such boxes themselves. Before trials in the effect conditions started these black boxes were presented in an 8 seconds demonstration phase and participants were instructed to vividly keep the position and the width of the boxes in mind without moving. During experimental trials the box/boxes only appeared when participants reached the x-position of the inner edges of the (at this point in time not visible) boxes. In the instructions for the effect condition, participants were asked to produce such boxes of the same width and at the same position at their movement reversals. In both goal conditions, participants were asked to perform the task as fast and as accurately as possible.

At the beginning of the experiment participants received general instructions explaining all goal constellations and types of movements. Detailed instructions and visual stimuli were also presented on the screen before each trial. Participants started a trial themselves by entering the starting box, which appeared together with the instructions, with their pen whenever they were ready to begin. Trial duration was always 40 seconds.

Participants performed four training trials: two target condition trials and two effect conditions trials, each in the one goal constellation and the same goals constellation. The combination of three different goal constellations with two goal conditions, together with the balancing of the locations (left, right) of the standard box resulted in 12 experimental trials (in the same goals constellation the same number of trials as in the other constellations was conducted). Trials were presented in random order (restriction: not more than three trials of the same goal condition in a row). Participants completed 3 series of these 12 trials, after each of those series they had the opportunity to take a short break. The whole experiment took approximately 45 minutes.

2.1.4. Data Analysis

Raw data were smoothed with a nonlinear smoothing algorithm (Mottet, Bardy, & Athenes, 1994) by using weighted and moving medians in a 7 data point window. After that, pen velocity was determined at each measured point in time (i.e. every 5.8 ms) and then also smoothed with the same algorithm. The first 10 seconds of each trial were excluded from further analyses. For every goal condition in every goal constellation 6 trials were available for analysis. Since displacements on the y-axis were small (M = 0.29 cm, SD = 0.28 cm), only the maximum displacements on the x-axis were analyzed.

The reversal points (onsets and endpoints of a movement in one direction) were defined as the most leftwards or rightwards points of a movement followed by two data points indicating that the movement direction had changed. Movements were excluded from analysis if a) participants did not move continuously (not more than 1 mm within the first 50 ms of a movement), b) movement length was smaller than 5.3 cm (i.e. half of the instructed length of a movement) and c) participants did not cross the middle line of the screen. Using these criteria less than 1% of movements were excluded from analyses in both target and effect conditions. A preliminary data analysis indicated that there were no differences in the data patterns between movements to the left and the right side. Therefore data were collapsed over this factor. The following statistical procedures were applied to both experiments: a) if appropriate we report Greenhouse-Geisser corrected F values, b) only higher order effects are reported if the lower order effects cannot be interpreted on their own, c) significant effects were further analyzed using paired-sample t-Tests and d) if appropriate Bonferroni corrected p values are reported.

The following set of dependent variables was analyzed in both experiments. To characterize the shape of trajectory, the time to reach peak velocity relative to the complete duration of the movement (proportional time to peak velocity in %, PTPV), and the time spent on one movement relative to the time spent on the complete reversal movement (proportional movement time in %, PMT) were analyzed. To characterize temporal performance the duration of a whole reversal movement (in ms, RMT) was analyzed. To characterize spatial performance the variability around the average endpoint of a movement (in cm, EP_V) and movement distance on the x-axis (in cm, Dist_X) were calculated. PTPV, PMT, and EP_V were analyzed using 3x2x2 repeated measurements analyses of variances (ANOVAs) with the factors GoalConstellation (one goal, same goals, different goals), GoalCondition (targets, effects), and BoxType (standard, manipulated). Note that 'manipulated' in the factor BoxType can stand for no box (one goal constellation), the same standard box (same goals constellation), or the more difficult box (different goals constellation). RMT and Dist_X were subjected to 3 x 2 factors ANOVAs with the factors GoalConstellation (one goal, same goals, different goals) and GoalCondition (targets, effects), because those variables cannot be calculated separately for both sides of the reversal movement.

Furthermore, we calculated effective Index of Difficulty (eID) using effective target width (Welford 1968; Zhai, Kong, & Ren, 2004). In order to analyze whether the same amount of variance is explained by Fitt's Law in target and effect conditions, we used eID and movement time (MT) of every condition and computed correlations between eID and MT for every participant. The individual correlations were z-transformed (Fisher's *z*-transformation). T-tests were run on those transformed values. The average correlations reported here in the text are reconverted from the average Fisher's *z*-values. We also calculated individual linear regression functions for each participant and each goal condition (target, effect) and used the estimated β values and intercepts for post-hoc t-Test analyses.

As our hypotheses partly consist of null-hypotheses (i.e. we expect no significant differences between target- and effect-directed movements) we calculated confidence intervals in order to assess whether differences between the two conditions are likely to be meaningful (Loftus, 1996). Confidence intervals for within-participant designs were calculated from normalized data according to Cousineau (2005), with the correction procedure suggested by Morey (2008). To gain further evidence for a functional similarity of target- and effect-directed movements we also calculated Pearson correlations between target and effect conditions for PTPV and PMT for each participant. Individual correlations were Fisher-z-transformed and the average correlation coefficients reported here are reconverted from the average Fisher´s z-value.

2.2. Results

2.2.1. Shape of trajectory

Proportional time to peak velocity (PTPV, see Figure 3.2). There was a significant interaction between GoalConstellation and BoxType, $F(2, 38) = 17.16$, $p< .001$, $\eta^2_p =$ .48. In the one goal constellation PTPV was lower when moving towards the standard box (*M* = 41.7 %) than when moving away from it to the no box side (*M* = 45.3 %). In the different goals constellation the opposite pattern was observed: when moving towards the more difficult box, PTPV was lower (*M* = 35 %) than when moving towards the standard box (*M* = 42.7 %). No such difference between the sides was observed in the same goals constellation. There were no significant main effect of and no significant interactions with the factor GoalCondition, indicating that effect- and target-direction movements were performed in a similar way. The average correlation between target conditions and effect conditions was high (r = .78) also pointing to a functional similarity between them.

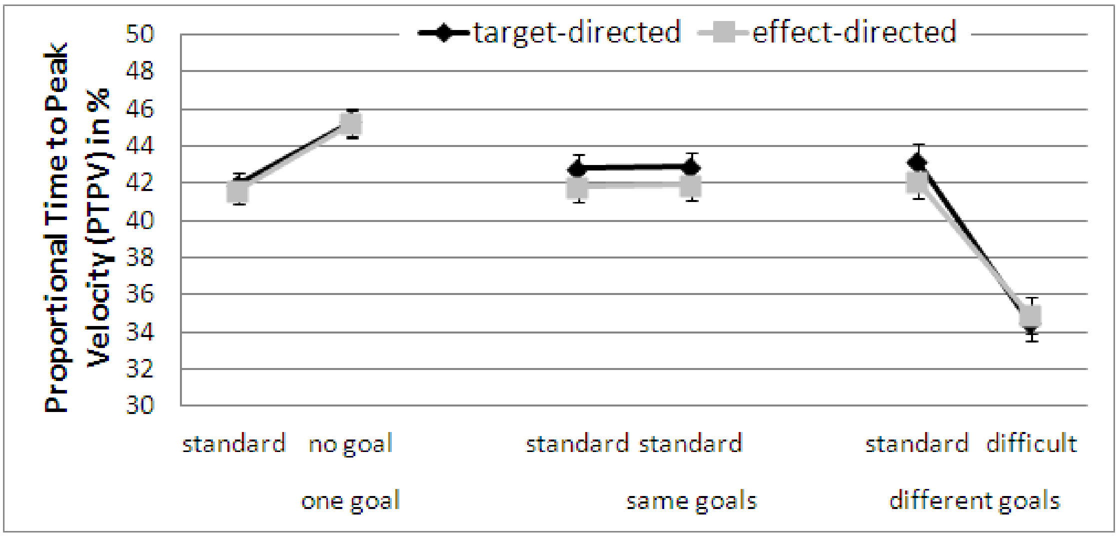

Figure 3.2. Experiment 1. Means and confidence intervals of Proportional Time to Peak Velocity in % (PTPV).

Proportional Movement Time (PMT, see Figure 3.3). A significant interaction between GoalConstellation and BoxType, $F(2, 38) = 10.94$, $p < .001$, $\eta_p^2 = .37$ was observed. In the one goal constellation PMT was higher for movements towards the standard box ($M = 51.4$) in comparison to movements to the no box side ($M = 48.6$ %). The reverse pattern was observed in the different goals constellation. Here PMT towards the more difficult box was higher ($M = 52.9$ %) than towards the standard box ($M = 47.1$ %). No such difference between the sides was present in the same goals constellation. Again, there were no significant main effect of and no significant interactions with the factor GoalCondition. Further, again the average correlation between target and effect conditions was high (r = .89).

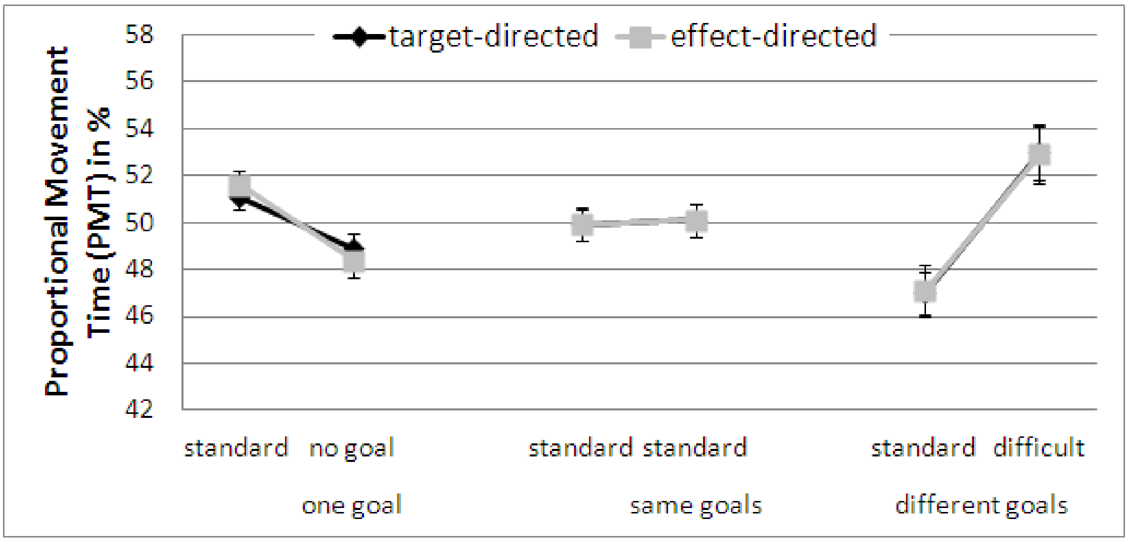

Figure 3.3. Experiment 1. Means and confidence intervals of Proportional Movement Time in % (PMT).

2.2.2. Temporal Performance

Reversal Movement Time (RMT, see Table 3.1) There was a significant main effect of GoalConstellation, $F(2, 38) = 13.84$, $p < .001$, $\eta_p^2 = .42$. RMT in the one goal constellation (M = 1071 ms) did not differ significantly from RMT in the same goals constellation (*M* = 1137 ms), but RMT in the different goals constellation (M = 1415 ms) was significantly higher than in both other constellations ($p < .05$). This finding can be attributed to the presence of a more difficult spatial goal in this constellation than in the other constellations. A significant main effect of GoalCondition, $F(1, 18) = 9.54$, $p < .006$, $\eta_p^2 = .33$, indicated that RMT was higher in effect-directed movements (*M* = 1245 ms) than in target-directed movements (*M* = 1171 ms).

Table

3.1. Experiment 1. Variables describing temporal and spatial performance. Means and confidence intervals (in parenthesis) of Reversal Movement Time in ms (RMT), Endpoint Variability in cm (EP_V), and Movement Distance on the x-axis in cm (Dist_X).

	One goal		Same goals		Different goals	
	M (CI)		M (CI)		M (CI)	
Reversal movement time in ms (RMT)						
target-directed	1045 (391)		1103 (588)		1365 (892)	
effect-directed	1097 (495)		1172 (601)		1465 (472)	
Endpoint variability in cm (EP_V)						
	Standard	Manipulated	standard	manipulated	standard	manipulated
target-directed	0.53 (0.1)	0.85 (0.1)	0.6 (0.1)	0.6 (0.1)	0.54 (0.1)	0.43 (0.1)
effect-directed	0.56 (0.1)	0.82 (0.1)	0.57 (0.1)	0.59 (0.1)	0.56 (0.1)	0.51 (0.1)
Movement distance on the x-axis in cm (Dist_X)						
target-directed	10.8 (0.15)		10.9 (0.12)		10.9 (0.11)	

effect-directed	10.6 (0.15)	10.8 (0.12)	10.9 (0.13)

2.2.3. Spatial Performance

Endpoint Variability (EP_V, see Table 3.1). There was a significant GoalConstellation X BoxType interaction, *F*(2, 38) = 14.84, *p*< .001, η_p^2 = .44, that indicates that in the one goal constellation movements towards the side with the standard box (*M* = 0.54 cm) had a lower EP_V than movements to the no box side (*M* = 0.84 cm). In contrast, in the different goals constellation lower EP_V was observed in movements towards the more difficult box (M = 0.47 cm) in comparison to movements towards the standard box (*M* = 0.55 cm; all *p* < .05).

Movement Amplitude on the x-axis (MA, see Table 3.1). There was a main effect of GoalCondition, *F*(1, 19) = 5.9, *p*< .025, η_p^2 = .24.Target-directed movements (*M* = 10.9 cm) had higher MA than effect-directed movements (*M* = 10.7 cm).

Functions according to Fitts'Law (see Figure 3.4). The correlation eID and MT was *r* = .30 in the effect conditions and *r* = .38 in the target condition. These correlations did not significantly differ from each other, t(19) = 1.12, *p* > .05, indicating that the amount of variance explained by a linear relationship between eID and MT did not significantly differ between both types of movement. Fitting functions were also similar: β values, t(19) = -.74, *p* > .05, and intercepts, t(19) = .82, *p* > .05, did not significantly differ between the target condition [R^2 = .46, *p* < .05; *M* [β] = 208, *SD* = 160; *M* [intercept] = 41, *SD* = 341) and effect condition (R^2 = .54, *p* < .05; *M* [β] = 302, *SD* = 514; *M* [intercept] = - 319, *SD* = 1850].

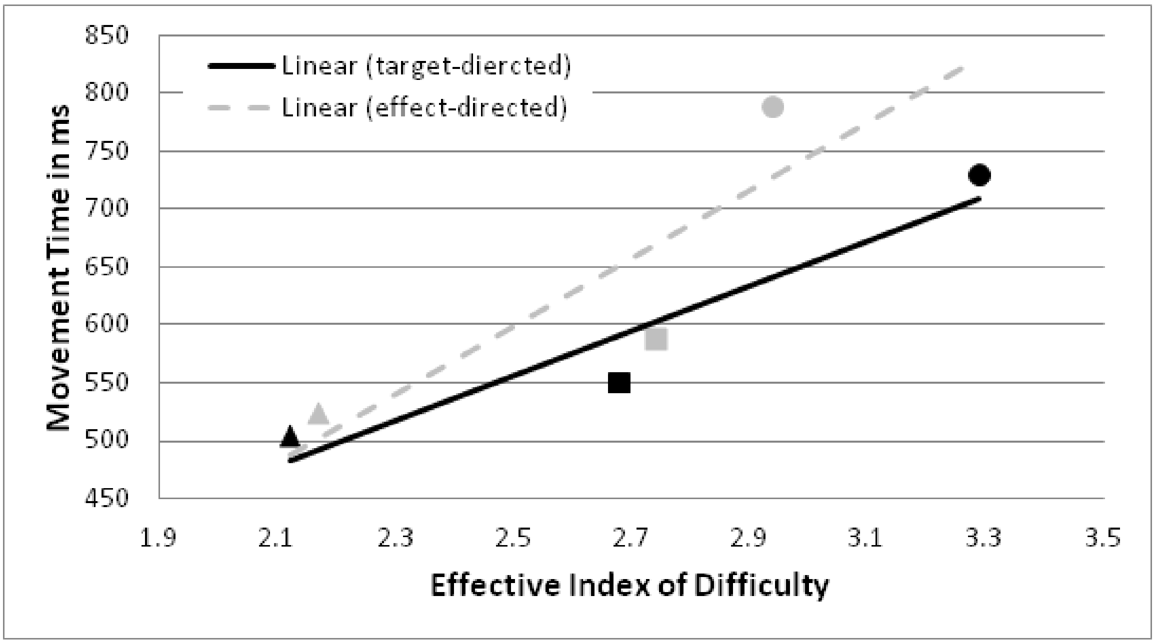

Figure 3.4. Experiment 1. Means and linear functions of the relation between effective Index of difficulty (eID) and movement time (MT in ms) for target-directed and effect-directed movements towards the manipulated goal. Triangles symbolize the one goal constellation, squares the same goals constellation, and circles the different goals constellation. Black markers indicate target conditions, grey markers indicate effect conditions.

2.3. Discussion

We conducted Experiment 1 in order to find out whether similar mechanisms of action control underlie movements towards presented visual-spatial targets and self-produced visual-spatial effects. Overall the data show that the movement kinematics are very similar in target- and effect-directed actions. We observed no main effect of GoalCondition and no interactions with the factor GoalCondition in PTPV and PMT. Both movement types can be equally well described by a linear Fitts´ function, and the functions were not significantly different from each other. Moreover, no differences in EP_V between both movement types were observed. A typical relative spatial kinematic pattern was obtained in the one goal constellation: when moving towards the standard box PTPV was lower and PMT was higher than when moving to the no box side. This pattern reverses in the different goals constellation: here PTPV was lower and PMT was higher when moving towards the manipulated (more difficult) box side than when moving towards the standard box side. Spatial variability as described by EP_V follows the same pattern: in the one goal constellation movements towards the manipulated box side (no box) have higher EP_V, in the different goals constellation movements towards the standard box side have higher EP_V. In the different goal constellation movements have also a longer RMT. Small differences between target-directed and effect-directed movements were also obtained. Effect-directed movements have higher RMT and smaller movement amplitudes on the x-axis than target-directed movements.

As expected, target-directed and effect-directed movements are performed in a similar way. When comparing movements towards a spatial goal with movements towards a side without a goal a typical spatial kinematic pattern (low PTPV, high PMT) emerges no matter if aiming towards a spatial target or producing a spatial effect. For both types of movement it can therefore be assumed that this kinematic pattern reflects the specific goal characteristics (here: spatial characteristics) and helps to achieve the goal of the movement (to perform movements spatially accurate). It has been speculated that the additional time in the target area at the end of the movement helps to improve spatial accuracy (Rieger, 2007; Elliott et al, 2001; Novak et al, 2000). Another hint for this assumption comes from studies showing that the skewness in velocity profiles increases as spatial accuracy demands increase and/or targets are small (Elliott et al, 2001; Helsen, Elliott, Starkes, & Ricker, 1998; Hogan & Flash, 1987; MacKenzie, Marteniuk, Dugas, Liske, & Eickmeier, 1987). Whereas this kinematic pattern has previously been observed in studies in which target-directed movements were investigated (Rieger, 2007; Elliott et al, 2001), we were able to demonstrate that it also occurs with effect-directed movements. The observation that both target-directed and effect-directed movements can be equally well described by a linear Fitts´ function, and that the functions do not significantly differ from each other, also points to a functional similarity of both as goals of an action. Surprisingly, no differences in EP_V between both movement types were found. Thus, even though participants have to remember location and width in effect conditions they seem to fulfill this task quite well. In the different goals condition they show lower EP_V towards the more difficult goal side in both conditions. This result, together with the data on the shape of the trajectories suggests, that participants do not only represent target location but also target width in effect conditions.

Differences between both types of movement were also found: Effect-directed movements have higher RMT and slightly shorter amplitudes (0.2 cm) than target-directed movements. Thus, even though the general movement *pattern* is the same as in target-directed movements, the data also point to differences between targets and effects. Those differences probably arise from higher cognitive demands in effect conditions: the need to remember the location of the effects, which may result in less precise goal representations. Those less precise goal representations may be compensated by longer movement times and slightly shorter amplitudes.

To sum up, target-directed and effect-directed movements seem to be controlled in a similar manner. Movement execution is thereby influenced by the upcoming goal *before* the effect appears or the target is reached, indicating that goal anticipations are important for the way how a movement is executed. Differences between target- and effect-directed actions can be attributed to higher cognitive demands in effect conditions.

3. Experiment 2

Results of Experiment 1 indicated that spatial kinematics are comparable in target- and effect- directed movements to visual-spatial goals, pointing to similarities in their control mechanisms. However, data also indicated that effects are represented less precisely, probably due to higher cognitive demands. Whereas in Experiment 1 we compared movements towards targets and effects performed in different trials, in Experiment 2 we combined target-directed and effect-directed movements within trials (a target on one side of the reversal movement, an effect on the other side of the reversal movement). We expected that a direct comparison of target- and effect-directed movements within one trial may enhance differences between them. When participants are asked to move to targets and effects within one goal constellation, one of those goals may be dominant (i.e. result in a more pronounced representation) over the other goal. Further, this setup prevents that participants move at different overall speed levels and also prevents shorter movement amplitudes in effect-directed than in target-directed movements (as it was the case in Experiment 1).

Participants again performed continuous reversal movements on the medial lateral axis to visual-spatial goals. There were four conditions: a) target-directed movements on both reversal sides, b) effect-direct movements on both reversal sides, c) target-directed movements to the left side and effect-directed movements to the right side, and d) target-directed movements to the right side and effect-directed movements to the left side.

Our hypotheses concerning the conditions with different goals on both sides of the reversal movement were undirected. On the one hand, the goal representation for the spatial target may be more pronounced than for the spatial effect, because the target is constantly visible. If this is the case, a more pronounced spatial kinematic pattern for the target side should be observed (higher PMT, lower PTPV in target-directed movements). On the other hand, as effect conditions seem more difficult, participants may devote more of their cognitive resources to the effect and thus, the effect representation may be more pronounced than the target representation. If this is the case, effect-directed movements should show a more pronounced spatial kinematic pattern (higher PMT, lower PTPV in effect-directed movements). We further expected, based on the results of the same goals constellation condition in Experiment 1, that no differences in movement kinematics between targets and effects occurs when the same type of movement is conducted towards both sides.

3.1. Method

3.1.1. Participants

20 healthy participants (11 female; mean age = 23.7 years, SD = 3.0) took part. According to the Edinburgh Inventory (Oldfield, 1971) all of them were right-handed (mean laterality quotient = 94, SD = 10). All of them reported normal or corrected-to-normal vision. They gave informed consent and received 7 Euro for participation. None of them had participated in Experiment 1.

3.1.2. Materials and Apparatus

The experimental setup was the same as in Experiment 1. Therefore only differences are reported here. Visual stimuli consisted the standard boxes of Experiment 1 (black boxes, width: 2 cm, height: 9 cm, ID = 2.7, presented 5.3 cm to left and to the right of the middle of the screen).

3.1.3. Procedure and Design

Visual-spatial goals were presented in four different goal combinations: Two with same goals which were a) target-directed movements on both reversal sides (target condition), and b) effect-direct movements on both reversal sides (effect condition), and two with different goals which were c) target-directed movements to the left and effect-directed movements to the right side, and d) target-directed movements to the right and effect-directed movements to the left side (see Figure 3.1, right panel).

As in Experiment 1 participants were instructed to perform target-directed and effect-directed movements. In conditions in which targets and effects were combined participants were asked to reverse the endpoints of their movements within the constantly presented black box on one side. When performing effect-directed movements, participants were asked to produce such boxes themselves as in Experiment 1. Each condition was preceded by instructions and an 8 second demonstration phase of the widths and positions of the boxes. Participants were instructed to keep those vividly in mind and to produce them in the effect conditions during the experimental trials. Trial duration was always 40 seconds.

Each of the 4 goal combinations was conducted 5 times resulting in 20 experimental trials. Before the experimental trials were conducted participants performed 4 training trials, one in each condition. Trials were presented in random order with the exception that not more than 3 trials of the same condition were performed consecutively.

3.1.4. Data Analyses

Data preparation was conducted as in Experiment 1. The first ten seconds of the each experimental trial were excluded from further analyses. As again displacements on the y-axis were small (M = 0.43 cm, SD = 0.41 cm) only displacements on the x-axis were analyzed. The same exclusion criteria as in Experiment 1 were applied, leading to exclusion rates of less than 1% in each condition. Because the data patterns for movements to the left and right side were similar, data were collapsed over this factor. PTPV and PMT were analyzed using 2 x 2 repeated measurement ANOVAs with the factors GoalConstellation (same goals, different goals) and GoalCondition (targets, effects). RMT and Dist_X were subjected to ANOVAs with the factor GoalConstellation (same targets, same effects, different goals).

3.2. Results

3.2.1. Shape of trajectory

Proportional time to peak velocity (PTPV, see Figure 3.5) There was a significant interaction between GoalConstellation and GoalCondition, $F(1, 19) = 12.1$, $p < .003$, $\eta_p^2 = .34$. In the same goals constellation target- and effect-directed movements did not significantly differ in PTPV, whereas in the different goals constellation PTPV was significantly lower for effect-directed ($M = 44.5$ %) than for target-directed ($M = 48.1$ %; $p < .05$) movements.

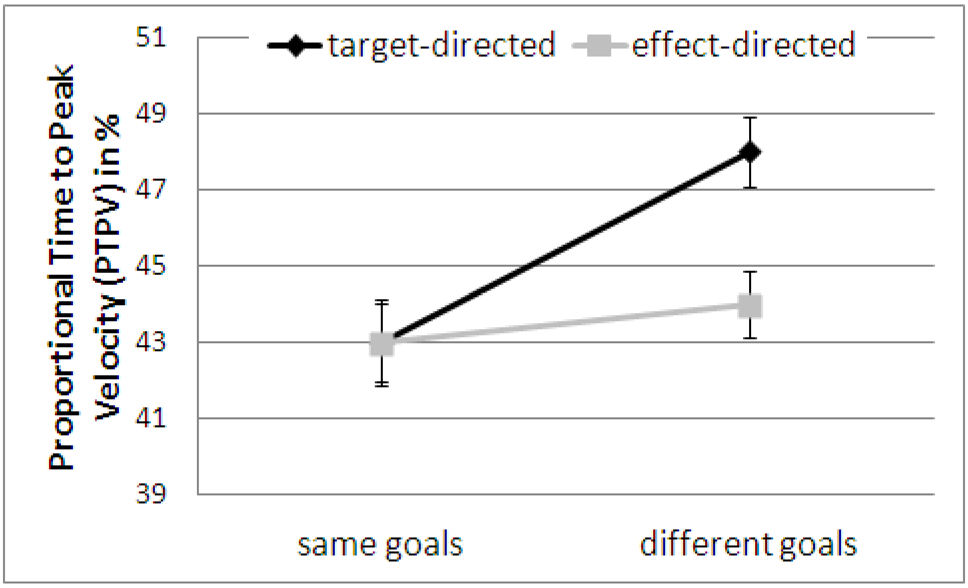

Figure 3.5. Experiment 2. Means and confidence intervals of Proportional Time to Peak Velocity in % (PTPV).

Proportional movement time (PMT, see Figure 3.6). A significant interaction between GoalConstellation and GoalCondition, $F(1, 19) = 8.0$, $p < .011$, $\eta_p^2 = .3$, indicated that target-directed movements ($M = 49$ %) had lower PMT than effect-directed movements ($M = 51$%) in different goals constellation, whereas no difference between the two types of movement was observed in same goals constellation.

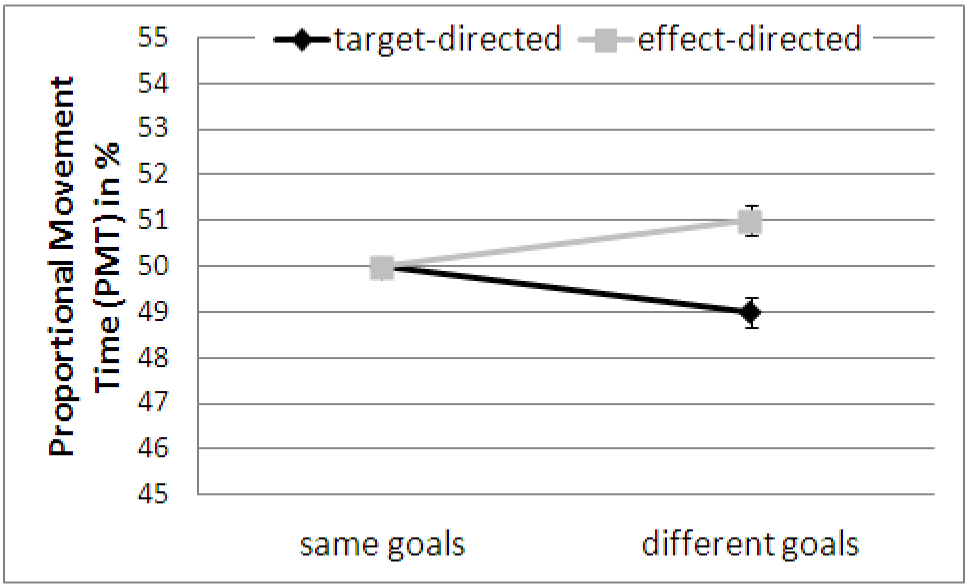

Figure 3.6. Experiment 2. Means and confidence intervals of Proportional Movement Time in % (PMT).

3.2.2. Temporal performance

Reversal movement time (RMT, see Table 3.2). The main effect of GoalConstellation was significant, $F(2, 38) = 4.1$, $p < .024$, $\eta_p^2 = .18$. Results were intransitive, only reversal movements in the same effects constellation took significantly longer (M = 947 ms) than movements in the different goals constellation (M = 809 ms, $p < .05$), whereas movements in the same targets constellation did not significantly differ from the other two conditions.

Table 3.2. Experiment 2. Variables describing temporal and spatial performance. Means and confidence intervals (in parenthesis) of Reversal Movement Time in ms (RMT), Endpoint Variability in cm (EP_V), and Movement Distance on the x-axis in cm (Dist_X).

Same targets	Same effects	Different goals: targets	Different goals: effects
M (CI)	M (CI)	M (CI)	M (CI)
Reversal movement time (RMT)			
895 (30)	947 (31)	809 (21)	
Endpoint Variability in cm (EP_V)			
0.58 (0.006)	0.57 (0.006)	0.57 (0.005)	0.55 (0.006)
Movement Distance on the x-axis in cm (Dist_X)			
10.8 (0.12)	10.7 (0.12)	10.8 (0.12)	

3.2.3. Spatial performance

Endpoint variability (EP_V, see Table 3.2). There were no significant main effects or interactions.

Movement distance on the x-axis (Dist_X, see Table 3.2). There were no significant main effects or interactions, showing that participants moved comparable distances in all conditions.

3.3. Discussion

In order to enhance differences between effect-directed and target-directed movements, they were executed within the same reversal movement in one of the goal constellations of Experiment 2. Results of variables describing the shape of trajectory show that a more pronounced spatial kinematic pattern emerged in the different goals constellation towards effect-directed movements (lower PTPV, higher PMT). As expected, no significant differences were found in the same goals constellation. However, in the same effects constellation higher RMT were observed than in the different goals constellation. No significant effects were found in variables describing the spatial performance (EP_V and Dist_X).

As expected, based on the results of Experiment 1, no significant differences in shape of trajectory between target and effect conditions in the same goals constellation were observed. This provides further evidence for the functional equivalence of targets and effects as action goals. Interestingly, combining target- and effect-directed movements in one reversal movement enhanced differences between them: a more pronounced spatial kinematic pattern for effect-directed in comparison to target-directed movements was observed. Results of Experiment 1 suggested that effects have a less precise internal representation than targets. Thus, not the goal information provided by the experimental context (more precise in targets than in effects), but rather the cognitive resources devoted to the goal (more effortful for effects than targets) results in a more pronounced goal representation. This is in line with assumptions that movement kinematics are chosen in order to fulfill the task goals as well as possible (Rieger, 2007). In the same effects constellation significantly higher movement time was observed, again underpinning the assumption that effects are represented less precise and are therefore more difficult to perform, which is then compensated with higher movement times.

In summary, results of Experiment 2 again indicate that targets and effects are represented as action goals. However, less precise representation of effects is compensated by devoting more cognitive resources to effects, resulting in a more pronounced spatial kinematic pattern.

4. General Discussion

We conducted the present study in order to investigate whether spatial targets and spatial effects play a comparable role in action control as action goals. This was done by analyzing *how* participants execute movements towards visual-spatial targets and visual-spatial effects. In two different experiments participants performed continuous reversal movements towards targets, effects or no goals. In Experiment 1 target-directed and effect-directed movements were compared across conditions in three constellations with varying goal features. In Experiment 2 both movement types were combined within one condition to enhance differences between them. Results indicated that the same mechanisms of action control underlie movements towards targets and effects, and that they are therefore equally represented as action goals. When compared across conditions no significant differences between targets and effects were observed in the shape of the trajectory (Experiment 1, and Experiment 2, same goals constellation) and in spatial variability (Experiment 1 and 2). Further, target- and effect-directed movements both show a more pronounced spatial kinematic pattern towards a goal than towards a no-goal (Experiment 1, one goal constellation). Similarly, both show a more pronounced spatial kinematic pattern towards a more difficult than towards an easier goal (Experiment 1, different goals constellation). In addition, both target-directed and effect-directed movements can be equally well described by Fitts´ Law (Experiment 1). Differences between target- and effect-directed movements were observed when compared within conditions. Here effect-directed movements showed a more pronounced spatial kinematic pattern (Experiment 2). Effect-directed movements require that participants remember the effect location and use the remembered information to plan, initiate, and execute their aiming movement. To compensate for this less precise representation participants devote more cognitive resources to the effects. The higher cognitive demands also result in longer movement times towards effects (Experiment 1, and Experiment 2, same effects constellation).

One may argue that participants simply produced repetitive movements of similar amplitudes towards the same locations in both, target and effect conditions. We intentionally designed target and effect conditions as similar as possible, as we wanted to avoid that other differences in the characteristics of targets and effects (apart from being a target or a effect) can account for the results. Thus, targets and effects only differed in one decisive aspect: targets did not depend on the action of the participant (i.e. they were always visible), whereas effects dependent on the action of the participant (i.e. appeared when participants reached the target area). As the target stimulus and the effect stimulus were physically the same, and due to experiencing the stimulus as a target in 50% of trials, one may be concerned that participants' experience of the effect as being self-produced may be reduced. This may have been the case if participants had repeatedly switched between target and effect conditions. However, in our experiments one trial always lasted for 40 seconds, which resulted in a stable current context (target or effect context) for the stimulus. Moreover, when combined within one trial (Experiment 2) differences between target-directed and effect-directed movements were enhanced. This indicates that participants indeed experienced target and effect conditions as different.

One may also be tempted to compare the visual effects in our study with what is termed visual feedback in other studies (e.g. Thaler & Goodall, 2011; Roerdink, Peper, & Beek, 2005; Saunders & Knill, 2004). From a theoretical viewpoint, this is valid, because feedback certainly is an action effect. However, action effects in our study (appearance of a visual stimulus) were operationalized as the major goal of one reversal movement. In other studies investigating visual feedback the main purpose of a task is often not to "produce" the visual stimulus, but the visual feedback provides additional information about the current position. In addition to visual effects, participants also received visual feedback in our study: their current movement position was represented as a blue dot on the screen. Even though 'effects' and 'feedback' theoretically represent action effects, one may thus argue that the visual effects in our study (appearance of the boxes) reside on a higher level in the goal hierarchy of the task than visual feedback (cursor representing the current hand position), as it is the main purpose of the movement (or more specifically: the endpoint of the movement) to produce the effect which thus is the distal goal representation. It should be noted that in target conditions, participants also received visual feedback (cursor representing the current hand position). In target and effect conditions participants also received the same proximal effects/feedback (i.e. proprioceptive, kinesthetic). However, in target conditions participants received no visual effect. Rather, here the distal goal representation was to be at a certain position at a certain time.

Our results support the assumption that effect-directed movements are more difficult due to higher cognitive demands and that this is compensated by devoting more cognitive resources towards effects leading to a pronounced spatial kinematic pattern towards them. In line with this assumption are findings which indicate that (perceived) task difficulty influences movement kinematics. For example, Park & Kim (2008) manipulated target size and movement amplitudes in a Fitts' task separately such that both manipulations resulted in the same indices of difficulty. They investigated self-terminated horizontal elbow-extension movements. The authors found different mechanisms of movement control leading to an increase of movement time in both conditions. In the target-size condition a decrease in triceps and biceps muscle activation, and a decrease in movement velocity with increasing index of difficulty was observed in both, the acceleration and the deceleration phase. In the movement-amplitude condition triceps activation after movement onset and biceps activation during deceleration increased with increasing index of difficulty, resulting in a higher peak velocity, even though movement time also increased with increasing index of difficulty. Thus, they conclude that perceived task difficulty influences movement control, but not de facto task difficulty (held constant across conditions). Further, in a spatial aiming task reaction time and movement time to a first target increased as a function of the number of elements only when either the full response or the number of elements that have to be performed were specified in advance of the starting stimulus (Khan, Mourton, Buckolz & Franks, 2007). Khan et al conclude that when the number of to be performed elements is known in advance more complex movement integration strategies are preprogrammed, which leads to increased executive control and in turn results in longer reaction times as well as longer movement times. Along these lines we assume that higher cognitive demands in effect-directed movements are compensated by devoting more cognitive resources towards effects. This results in a more careful strategy of movement execution and leads to a more pronounced spatial kinematic pattern in effect-directed movements when they are combined with target-directed movements

Besides that effect-directed movements are more difficult to perform, the here presented experiments show that both target-directed and effect-directed movements show a typical spatial kinematic pattern towards visual-spatial goals. We take this as evidence that both targets and effects can be viewed as goals of an action. In the case of effects the goal of the action is the production of the effect itself and in the case of targets the goal is "to be at a certain place". We assume that the representation of these goals shapes movement kinematics in the observed typical manner. As these goal representations are being formed *before* the movement is actually conducted and then influence its execution this is in accordance with ideomotor principles of action control, claiming that the anticipation of the intended consequences of an action influences movement selection (Knuf, Aschersleben & Prinz, 2001), initiation (Kunde, 2003), and also movement execution (Kunde et al, 2004). So far ideomotor theories mainly deal with action effects as action goals. Besides the possibility that proximal effects are produced at action targets (e.g. tactile sensations or sensations related to body postures) targets are neglected. In contrast, our study shows that both targets and effects may equally serve as action goals, evoking visual-spatial event anticipations. Ideomotor theories should thus be expanded to cover goal-based (including target- and effect-based), rather than only effect-based action control.

Both the here presented study and our study conducted with auditory-temporal goals (Walter & Rieger, 2012) show that the same mechanisms of action control underlie movements towards targets and effects as they can both be seen as goals of an action. This comparable result presented here is not obvious, as differences in the way spatially and temporally restricted movements are controlled are observed in some studies (e.g. Maslovat et al, 2011; Franz et al, 1993; Heuer, 1993). The findings of Walter & Rieger (2012) as well as the current study indicate that the equivalence of targets and effects as action goals holds for spatially as well as temporally restricted movements. This may also be the case in other modalities.

Note that the interpretation of our data relies partly on nonsignificant results. However, traditional null hypothesis testing does not tell us the probability that the null hypothesis is true (Cohen, 1994). Thus, drawing strong conclusions from nonsignificant results may be problematic. However, the very small confidence intervals, which indicate that the true deviation from H0 is unlikely to be large, an a priori hypothesized pattern in the data, and the high average correlations between target and effect conditions in the variables describing the shape of the trajectory in Experiment 1 render our explanation, that similar mechanisms of action control underlie target- and effect-directed actions, very likely."

Besides this general similarity in spatially and temporally restricted movements there is also a difference in the results from both studies: combining targets and effects within one reversal movement increased differences between effect- and target-directed movements towards spatial goals in the present study, whereas the same manipulation enhanced similarities between effect- and target-directed towards temporal goals in the previous study (Walter & Rieger, 2012). A reason for this can be that spatial targets and effects and temporal targets and effects may pose different demands on the cognitive-motor system. Spatial targets can be perceived all the time during a movement, whereas spatial effects cannot. In contrast, temporal targets and effects both only occur for a limited amount of time. Updating of timing in temporal targets can only occur at those points in time, whereas updating of the position of spatial targets can occur at any time. Thus, temporal targets and effects may be more alike in their degree of difficulty than spatial targets and effects. Consequently, when combined within one condition differences between temporal targets and effects are diminished as their similarity is then emphasized, whereas differences between spatial targets and effects are enhanced as they become more obvious, resulting in a more pronounced spatial kinematic pattern towards effects.

To conclude, movement kinematics towards spatial targets and spatial effects are shaped in a typical manner showing that both targets and effects can equally serve as action goals. Moreover, both target-directed and effect-directed movements can be described by Fitts´ Law in a similar manner. Only small differences are found between target-directed and effect-directed actions. When combined within one condition more cognitive resources are devoted to effect-directed than to target-directed movements leading to a more pronounced representation of effects. The influence of the anticipation of upcoming events on movement execution is in accordance with ideomotor theories of action control. Ideomotor theories should be expanded to include action targets as action goals similar to action effects and consequently cover goal-based, rather than effect-based action control.

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Chapter 4

Shaping movement trajectories: The roles of goal representations and physical target characteristics

Shortened Title: Manipulated goal representations

Manuscript in Preparation

Abstract

In the present study the role of goal representation and the role of presented targets for movement execution (i.e. the shape of movement trajectories) were investigated. Participants performed continuous reversal movements towards temporal and/or spatial targets. Spatial targets were always presented and temporal targets were manipulated. Temporal targets were either acoustically presented (presentation), participants were instructed to imagine them (imagery), or neither presented nor imagined (absence). Movement kinematics in the imagery condition resembled movement kinematics of the presentation condition, and differed from the absence condition when a temporal target existed for one side of the reversal movement but not the other. This was the case even though the stimuli in the imagery and the absence condition were the same. However, when a temporal target existed on both sides of the reversal movements, movement kinematics in all 3 conditions were similar, indicating that participants may automatically form temporal goal representations in continuous reversal movements, even if no targets are presented or imagined. Results further indicated that imagined targets are represented less precise than presented targets. In conclusion, movement kinematics are shaped by the way targets are represented as action goals, rather than by physically presented target properties. However, the presence of physical targets plays a role for the acuity of movement execution.

1. Introduction

Every day we perform goal-directed actions. Action goals can be as simple as reaching out in order to pick up something from a table or as complex as going to university in order to get a masters degree. Such goals differentiate an action from pure movement. When interacting with the environment it is often the goal of an action to be at a target, i.e. to be at a certain place at a certain point in time. For example, we have to run to a specific location to catch a ball or we synchronize our movements to the rhythm of a tune when dancing. Such spatial (where) and temporal (when) targets are usually externally generated and are crucial for movement organization. Traditionally, movement kinematics are thought to reflect physical properties (i.e. position and time) of such action targets. However, targets may also evoke intentional goals such as “to be at a certain position at a given time”. Therefore, movements towards targets are not mere reactions to target characteristics, but rather means to attain intended goals (Rieger, 2007a). The here presented experiment was conducted in order to disentangle the roles of goal representations and the role of physically presented targets for movement execution, i.e. the shape of movement trajectories. In the following the term *target* will be used to describe physical properties of the experimental situation. In contrast, the term *goal* will be used to reflect participants’ representation of that target combined with the intention to be at the target.

An important theoretical framework describing the role of goal representations for action control is the ideomotor theory. The ideomotor theory claims that an action is selected, initiated, and executed by the anticipation of its perceptual consequences (James, 1890/1981; Prinz, 1997, for a historical overview see Stock & Stock, 2004, for recent reviews see Nattkemper, Ziessler, & Frensch, 2010; Shin, Proctor, & Cabaldi, 2010). Actions and their perceivable sensory outcomes (action effects) become associated due to repeated contingent appearance of both (“action – effect bindings”, Elsner & Hommel, 2001, 2004; Hommel, Alonso, & Fuentes, 2003). Once actions and effects are bound together, anticipated effects can automatically evoke motor commands that are appropriate to achieve the desired perceptual consequences.

Broad empirical evidence has been found for the claims of ideomotor theory of action control. It has been shown that perception of previously learned action effects primes the corresponding action (e.g. Elsner & Hommel, 2001, 2004; Kunde, 2004; Drost, Rieger, Brass, Gunter, & Prinz, 2005; Paulus, van Dam, Hunnius, Lindemann & Bekkering, 2011) and that anticipated action effects influence movement selection, initiation and execution (e.g. Knuf, Aschersleben, & Prinz, 2001; Kunde, 2001, 2003; Kiesel & Hoffmann, 2004; Rieger, 2007b).

Many studies showed that previously learned action effects can prime subsequent actions. For example, when participants perform movements that are contingently followed by tones of different pitches (e.g. left hand key-presses are followed by high tones and right hand key-presses are followed by low tones) and subsequently theses tones are presented as primes, the respective key-press is automatically activated (Elsner & Hommel, 2001). This priming effect is not only observed if participants acquire the action-effect binding themselves. When participants observe another person pressing keys that are followed by tones of different pitches and subsequently perform key presses themselves the actions are primed by the presentation of those tones (Paulus et al, 2011). Kunde (2004) showed that response priming is also possible with subliminal action effects. These, and further studies (e.g. Drost et al., 2005; Kray, Eenshuistra. Kerstner, Weidema, & Hommel, 2006) demonstrate the close coupling of actions and effects.

In other studies the influence of anticipated action effects on movement selection, initiation and execution was investigated. It has been shown that participants select actions faster when they are followed by an action effect that is compatible with regards to its intensity (e.g. a soft key-press produces a quiet tone, or a forceful key-press produces a loud tone, respectively) than an action effect that is incompatible (e.g. a soft key-produces a loud tone, or a forceful key-press produces a quiet tone; Kunde, Koch, & Hoffmann, 2004). The facilitation effect in the compatible conditions is attributed to the anticipation of an intended perceptual effect influencing action selection *before* the action effect is actually produced. In the same study the authors showed that such effect anticipations have an influence not only on early (selection) and late phases (initiation) of action planning, but also on how the action is performed (execution). Compatibility effects were also shown between the temporal duration of actions and auditory effects (Kunde, 2003). These and other studies (e.g. Kiesel & Hoffmann, 2004; Keller & Koch, 2006; Rieger, 2007b; Janczyk, Skirde, Weigelt, & Kunde, 2009) provide evidence for the assumption that the perceptual consequences of an action are internally represented and tightly associated with the motor commands that are able to produce them.

Thus far, studies investigating assumptions derived from the ideomotor theory of action control have been mainly concerned with the role of action effects, and rarely with action targets. However, two recent studies indicate that the mechanisms of action control may be similar with target- and effect-directed movements and show that targets and effects can both be seen as goals of an action influencing movement execution by the anticipation of upcoming events (Walter & Rieger, 2012a, 2012b). Typical *temporal movement kinematics* (relatively late and high peak velocity, and relatively short movement times) emerged when participants synchronized movements with regularly presented tones (target-directed movements) or produced tones themselves (effect-directed movements, Walter & Rieger, 2012a).Typical *spatial movement kinematics* (relatively early and low peak velocity, and relatively long movement times) emerged when participants moved to spatial targets as well as when they produced spatial effects (Walter & Rieger, 2012b).

Thus, the studies comparing effect-directed and target-directed movements show that in target-directed movements, movement kinematics are shaped by anticipated events like in effect-directed movements. In the present study we wanted to investigate the representation of anticipated events in target-directed movements further. In particular, we ask the question, whether the physical characteristics of those events shape movement kinematics or their cognitive representation. Rieger (2007a) addressed the question of the influence of goal representations and physical target properties on movement kinematics by comparing movement kinematics of continuous reversal movements towards combinations of temporal and spatial targets and single targets. She raised 3 hypotheses, how participants deal with the combination of spatial and temporal targets: a) the kinematic assimilation hypothesis, which states that participants show a mix of spatial and temporal kinematic patterns towards the combined target if they simply react to target characteristics, b) the relevance for performance hypothesis, which states that when one of the targets is easy (e.g. the temporal targets are separated by relatively long intervals), participants should be more concerned with the other target, and c) the goal representation hypothesis, which states that if participants represent one reversal side of the movement as the major goal side, meeting target demands (temporal and/or spatial) at the major goal-side as best as possible should take precedence over meeting the target demands at the other side of the movement. Results were in favour of the goal representation hypothesis. For example, when more time was available, stronger spatial kinematics were observed towards a combined spatial-temporal target than towards a single spatial target on the other reversal side.

In the present study we want to gain further evidence for the influence of internal goal representations on movement kinematics. One may criticize the previous experiments by Rieger (2007a), because goals that were represented as major goals of an action were combined goals (two targets) and therefore differed in their physical characteristics from minor goals (one target). Therefore, we chose a different approach to manipulate goal representations in the present experiment: we asked participants to imagine targets.

In detail, we compared the kinematics of movements towards auditory-temporal targets (isochronous rhythm) that were a) actually presented (presentation condition), b) imagined after a demonstration phase in which the requested rhythm was introduced (imagery condition), or c) neither presented nor imagined (absence condition). Visual-spatial targets were always presented. Participants were asked to perform continuous reversal movements and to reverse movement direction at the occurrence of the temporal targets and at the positions of the spatial targets.

Two different goal constellations were performed. In one constellation spatial targets were presented on both sides of the movement and one temporal target was additionally presented/imagined/absent on one side of the movement (two spatial/one temporal target constellation). In the other constellation a spatial target was presented on one side of the movement, and two temporal targets were presented/imagined/absent on both sides of the movement (one spatial/two temporal target constellation). These target combinations always resulted in a reversal side with a combined target and reversal side with a single target (see Figure 4.1, the absence condition is an exception here).

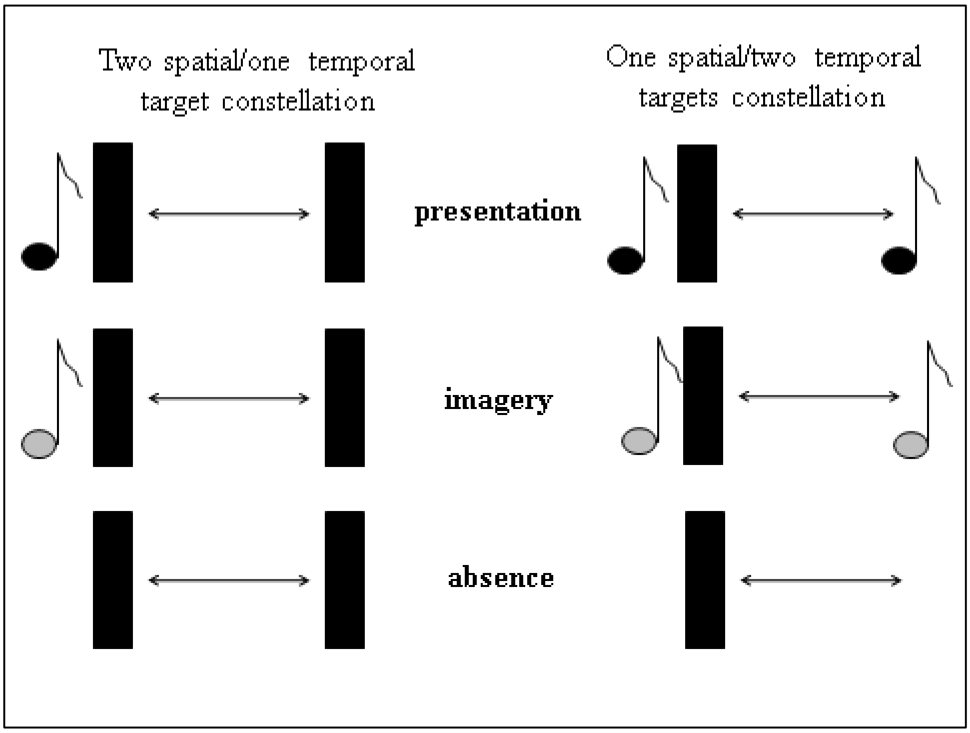


Figure 4.1. Overview of the experimental conditions. On the left side the two spatial/one temporal target constellation, and on the right side the one spatial/two temporal targets constellation are depicted. Black boxes represent physically presented spatial targets, black notes represent physically presented temporal targets, and grey notes represent imagined temporal targets.

Of major interest was whether the kinematic pattern in the imagery condition would be more similar to the presentation or to the absence condition. Physical characteristics of the imagery and the absence condition are the same, whereas goal representations of the imagery and the presentation condition are the same. Therefore, similar kinematics in the imagery condition and the presentation condition would indicate that goal representations rather than physical target characteristics shape movement kinematics. However similar kinematics in the imagery condition and the absence condition would indicate that physical target characteristics rather than goal representations shape movement kinematics.

We expected that in the presentation condition movements towards the combined target have a typical relative temporal kinematic pattern in fast tempo, which is more difficult, as the primary goal of participants may be to manage the synchronization task (focus on temporal target, Rieger, 2007a), and the asymmetric kinematic profile seems to help to achieve the timing goal of the task (Torre & Balasubramaniam, 2009). In slow tempo, which is easier, a typical relative spatial kinematic pattern should emerge, because participants are able to additionally focus on the spatial target (Rieger, 2007a). In the absence condition we expected a symmetrical kinematic pattern in the two spatial/one temporal target constellation and a typical spatial kinematic pattern towards the spatial target side when compared with the no-target side in the one spatial/two temporal target constellation. We expected that the shape of movement trajectories in the imagery condition would be more similar to the presentation than to the absence condition. However, we also expected some differences between the presentation condition and the imagery condition. Temporal targets that are presented provide precise temporal information that can be used for correcting temporal errors in following movements. Imagined targets in contrast rely solely on the once formed internal representation, which could become imprecise over time since updating of the temporal representation due to external events is not possible. This phenomenon known as drift is frequently observed in studies investigating sensory motor synchronization, for example when the task switches from a synchronization phase (finger tapping with a metronome switched on) to a continuation phase (with the metronome switched off, Ruspantini & Christolini, 2009; Vardy, Daffertshofer, & Beek, 2009). Therefore, we expected higher temporal variability in the imagery than in the presentation condition, and maybe less pronounced kinematic differences between movements towards the single and combined goal in the imagery condition.

2. Method

2.1. Participants

24 healthy participants (14 female) took part in this experiment. All of them were right-handed according to Edinburgh Inventory (Oldfield, 1971) with a mean laterality quotient of 95 (*SD* = 7). Their mean age was 24.0 years (*SD* = 3.1 years). All of them reported normal or corrected-to-normal vision. They gave informed consent prior to the experiment and received 14 Euro for participation.

2.2. Materials and Apparatus

Movements were recorded with a 30.5 cm x 45.5 cm Wacom Ultrapad A3 writing pad (resolution: 500 pixels per cm, sampling rate: 172 Hz) that was placed on a desk. Participants performed movements with their right (dominant) hand, which was shielded from view by a cover. They were able to see their movement trace consisting of a blue circle (4 mm in diameter) on a screen (17´´, resolution: 1024 x 768 pixels, vertical refresh rate: 100 Hz). Movement distance on the writing pad equaled movement distance on screen. The screen was placed behind the pad at a distance of 60 cm from the participants and 9 cm higher than the pad. Temporal targets consisted of 1000 Hz tones (54 dB) presented for 5 ms through loudspeakers placed to the left and the right of the screen. If no temporal targets were present a moving black circle (7 mm in diameter) indicated the approximate movement speed in a demonstration phase. Spatial stimuli consisted of black boxes (distance between the centers 10.6 cm, width: 2 cm, resulting in an index of difficulty, ID, of 2.7, Fitts, 1954) presented 5.3 cm to left and/or the right of the middle of the screen. If only one box was present a black line of 10.6 cm length aligned horizontally in the middle of the screen indicated the approximate length of a movement before the trials started. A red box (0.5 x 0.5 cm) presented in the middle of the screen served as a starting box.

2.3. *Procedure*

The experiment took place in a dimly lit room. Participants were asked to perform continuous reversal movements on the medial-lateral axis without pausing at the reversal points. They performed three different temporal target conditions that were presented blockwise: presentation, imagery and absence. In all three conditions participants reversed their movements on one (one spatial/two temporal targets constellation) or two (two spatial/one temporal target constellation) spatial targets that were constantly presented. In the presentation condition an isochronous rhythm was presented and participants were asked to synchronize the endpoints of their reversal movements on one side (two spatial/one temporal target constellation) or both sides (one spatial/two temporal targets constellation) with the temporal targets. In the imagery condition an isochronous rhythm was presented in a demonstration phase and participants were asked to keep it vividly in mind. During the experimental trials no rhythm was presented but participants were asked to vividly imagine the tones in the isochronous rhythm and to synchronize the endpoint of the movement reversals on one side (two spatial/one temporal target constellation) or on both sides (one spatial/two temporal targets constellation) with the imagined tones and to perform the reversals on the spatial targets (if present). The absence condition was preceded by a short demonstration phase, in which a black circle moved back and forth between the spatial target/s in the requested tempo at constant speed. Participants were asked to perform the reversal movements in the presented tempo during the experimental trials.

General instruction for all conditions stated that participants should move continuously back and forth. Participants were told that it was more important to be in synchrony with the presented/imagined tones than to be spatially accurate in the presentation and the imagery conditions. Instructions and visual stimuli were presented on the screen before each trial. Participants started a trial themselves by entering the starting box, which appeared together with the instructions, with their pen whenever they were ready to begin.

In the experimental trials a complete reversal movement was conducted in three different tempi: 1500 ms tempo (0.7 Hz), 750 ms tempo (1.3 Hz), and 500 ms tempo (2 Hz). Tempi were always presented in the same order starting with the slowest tempo, proceeding to the fastest tempo, and then becoming slower again (that is 1500 ms, 750 ms, 500 ms, 500 ms, 750 ms, 1500 ms). Thus, each tempo was performed in two experimental trials in each condition. Trial duration was set to be equivalent to the assumed duration 40 complete reversals resulting in 60 seconds (1500 ms tempo), 30 seconds (750 ms tempo), and 20 ms (500 ms tempo). The duration of the demonstration phase also depended on the tempo and was equivalent to 15 complete reversals, resulting in 22.5 seconds (1500 ms tempo), 11.25 seconds (750 ms tempo), and 7.5 seconds (500 ms tempo).

The combination of the two goal constellations together with the balancing of the location of the combined goal (left or right) resulted in 4 combinations per temporal target condition (presentation, imagery, absence), that is 12 combinations altogether. Each combination was preceded by a training trial conducted in 1000 ms tempo resulting in 7 trials within one combination. The order of the three temporal target conditions was counterbalanced across participants. Within the temporal target conditions each of the four possible location x goal constellation condition combinations was presented in random order.

2.4. Data Analysis

Raw data were smoothed with a nonlinear smoothing algorithm (Mottet, Bardy, & Athenes, 1994) by using weighted and moving medians in a 7 data point window. After that, pen velocity was determined at each measured point in time (i.e. every 5.8 ms) and then also smoothed with the same algorithm. The first 15 (1500 ms tempo), 7.5 (750 ms tempo) and 5 seconds (500 ms tempo) were excluded from each trial. As preliminary data analyses indicated no difference between the movement sides (left or right), data were collapsed over this factor. Thus, for each participant 4 trials were available for analysis in each tempo in each temporal target condition and in each goal constellation (in total 72 trials). Since displacements on the y-axis were small (two spatial/one temporal target constellation: M = 0.3 cm, SD = 0.3 cm; one spatial/two temporal targets constellation M = 0.27 cm, SD = 0.25 cm), only the maximum displacements on the x-axis were analyzed.

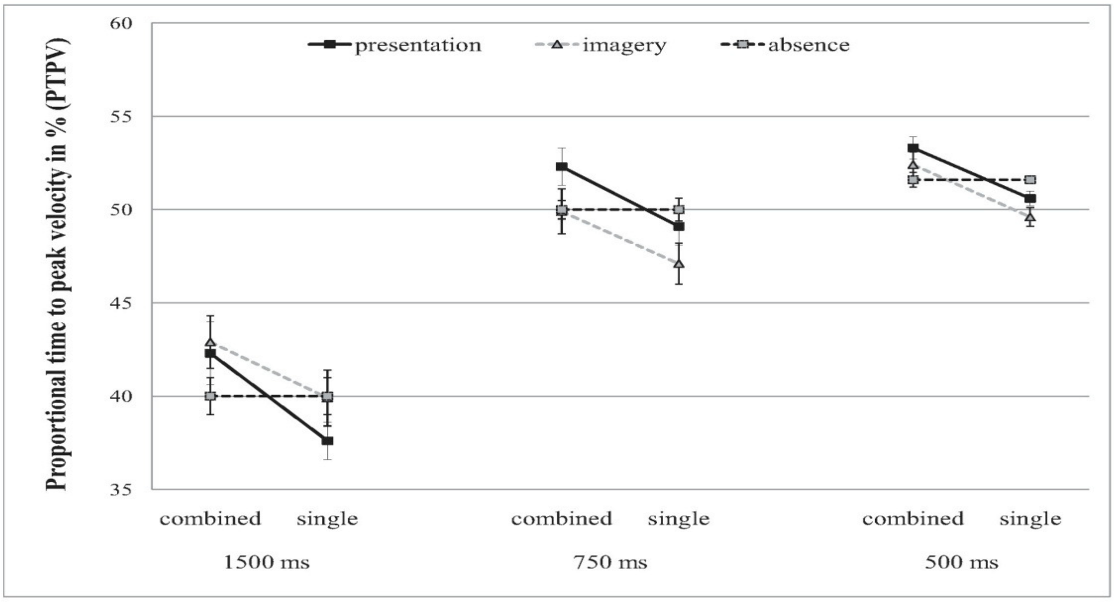
The reversal points (onsets and endpoints of a movement in one direction) were defined as the most leftwards or rightwards points of a movement followed by two data points indicating that the movement direction had changed. Movements were excluded from analysis if a) participants did not move continuously (not more than 1 mm within the first 50 ms of a movement), b) movement length was smaller than 2.7 cm (i.e. a quarter of the instructed approximate length), or c) movement time was more than two standard deviations longer or shorter than the individually calculated z-standardized values of movement time in each condition. Using these criteria on average 1.6% of trials in the presentation condition, 1.7% of trials in the imagery condition, and 0.3% of trials in the absence condition were dropped from analysis.

The following set of dependent variables was analyzed. To characterize the shape of trajectory, the time to reach peak velocity relative to the complete duration of the movement (proportional time to peak velocity in %, PTPV), and the time spent on one movement relative to the time spent on the complete reversal movement (proportional movement time in %, PMT) were analyzed. To characterize temporal and spatial variability, the variability around the average time of a reversal movement (reversal movement time variability in ms, RMT_V) and the variability around the average endpoint of the movements on the x-axis (endpoint variability in cm, EP_V) were analyzed. As a control variable we calculated the duration of a whole reversal movement (in ms, RMT). As we had no specific hypothesis about differences between the two goal constellations they were analyzed separately and the results will be presented and discussed separately in the following section. Dependent variables were analyzed using 3x3x2 repeated measurements analyses of variances (ANOVAs) with the factors TemporalTarget (presentation, imagery, absence), Tempo (1500 ms, 750 ms, 500 ms), and GoalType (combined, single). Note that the GoalType "single" stands for a spatial target in the two spatial/one temporal target constellation and a temporal target in the one spatial/two temporal targets constellation. RMT was tested against the instructed movement durations (1500 ms, 750 ms, and 500 ms) using one sample *t*-Tests with fixed values. The following statistical procedures were applied: a) if appropriate we report Greenhouse-Geisser corrected F and p values, b) only higher order effects are reported if the lower order effects cannot be interpreted on their own, c) significant effects were further analyzed using paired-sample t-Tests, and d) if appropriate Bonferroni corrected p values are reported.

3. Results and discussion: Two spatial/one temporal target constellation

3.1. Results

*Proportional time to peak velocity (PTPV, see Figure 4.2, upper panel).*A significant main effect of Tempo, $F(2, 46) = 152.5$, $p < .001$, $\eta^2_p = .87$, showed that PTPV increased with increasing tempo (1500 ms: $M = 40.8$ %, 750 ms: $M = 49.8$ ms, 500 ms: $M = 51.5$ ms, all $p < .001$). A significant TemporalTarget x Tempo interaction, $F(4, 92) = 3.93$, $p = .014$, $\eta^2_p = .15$, indicated that the difference between tempo 1500 ms and tempo 500 ms was significantly higher in the presentation ($M = -12.0$ %) than in the imagery condition ($M = -9.6$ %, $p < .05$). The absence condition ($M = -10.6$ %) differed from neither of the other conditions significantly ($p > .05$). Most importantly, the significant TemporalTarget x GoalType interaction, $F(4, 92) = 3.98$, $p = .025$, $\eta^2_p = .15$, showed that the same pattern of results was observed in the presentation and the imagery condition: PTPV was higher towards the combined goal (presentation $M = 49.3$ %, imagery $M = 48.4$ %,) than towards the single goal (presentation $M = 45.8$ %, imagery $M = 45.5$ %, both $p < .05$). In the absence condition no significant difference in PTPV between both movement sides was observed ($p > .05$).



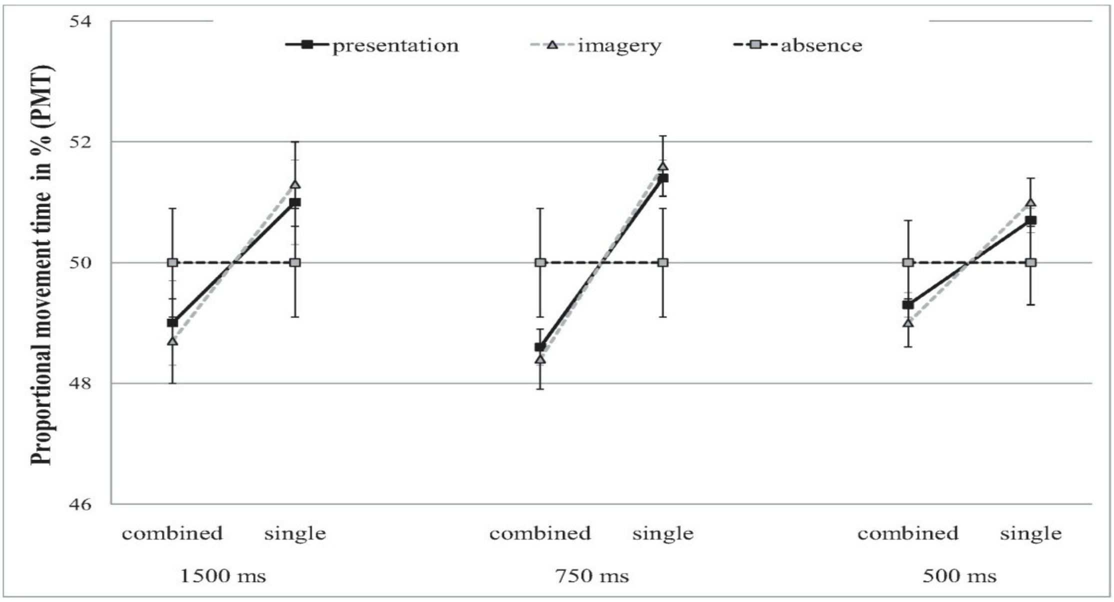


Figure 4.2. Two spatial/one temporal target constellation. Means and standard errors (error bars represent +/- 1 SE) of proportional time to peak velocity in % (PTPV) and proportional movement time in % (PMT), separately for the three temporal target conditions, the three tempi, and the two goal types.

Proportional Movement Time (PMT, see Figure 4.2, lower panel). There was a significant TemporalTarget x GoalType interaction, $F(4, 92) = 5.12$, $p = .021$, $\eta^2_p = .18$. Again the presentation and the imagery condition showed the same pattern: PMT was lower towards the combined goal (presentation $M = 49.0$ %, imagery $M = 48.7$ %) than towards the single goal (presentation $M = 51.0$ %, imagery $M = 51.3$ %, both $p < .05$), no significant difference between both reversal sides was observed in the absence condition ($p > .05$).

Reversal Movement Time Variability (RMT_V, see Table 4.1). A significant main effect of Tempo, $F(2, 46) = 98.61$, $p < .001$, $\eta^2_p = .81$, indicated that RMT_V decreased with increasing tempo (1500 ms: $M = 86$ ms, 750 ms: $M = 44$ ms, 500 ms: $M = 26$ ms). A significant main effect of TemporalTarget, $F(2, 46) = 4.89$, $p = .020$, $\eta^2_p = .18$, indicated RMT_V was significantly higher in the imagery condition ($M = 61$ ms) than in the presentation condition ($M = 41$ ms, $p < .05$). The absence condition ($M = 53$ ms) did not differ significantly from the other two conditions (both $p > .05$).

Table 4.1. Experiment 1. Two spatial /one temporal target constellation. Variables describing temporal and spatial performance. Means and standard errors (in parenthesis) of Reversal Movement Time Variability in ms (RMT_V), Reversal Movement Time in ms (RMT), and Endpoint Variability in cm (EP_V).

	1500 ms M (SE)		750 ms M (SE)		500 ms M (SE)	
	Single	combined	single	combined	Single	combine d
Reversal Movement Time Variability in ms (RMT_V)						
presentation	70 (5)	69 (4)	34 (4)	36 (3)	20 (5)	20 (3)
imagery	99 (12)	103 (13)	50 (6)	56 (5)	29 (3)	32 (4)
absence	88 (10)	88 (10)	43 (7)	43 (7)	27 (7)	27 (7)
Reversal Movement Time in ms (RMT)						
presentation	1479 (10)		754 (5)		511 (7)	
imagery	1420 (54)		825 (38)		596 (32)	
absence	1320 (54)		727 (50)		541 (28)	
Endpoint Variability in cm (EP_V)						
presentation	0.32 (0.02)	0.34 (0.02)	0.54 (0.03)	0.62 (0.03)	0.63 (0.03)	0.72 (0.03)
imagery	0.35 (0.03)	0.42 (0.04)	0.50 (0.04)	0.56 (0.04)	0.55 (0.04)	0.65 (0.04)
absence	0.37 (0.03)	0.3 7 (0.03)	0.56 (0.03)	0.60 (0.03)	0.61 (0.03)	0.60 (0.03)

Reversal Movement Time (RMT, see Table 4.1). In the imagery condition RMT was significantly longer than instructed in the 500 ms tempo ($p < .05$) and in the absence condition RMT was significantly shorter than instructed in the 1500 ms tempo ($p < .05$). In all other conditions RMT did not deviate significantly from the instructed durations.

Endpoint Variability (EP_V, see Table 4.1). A significant main effect of Tempo, $F(2, 46) = 127.0$, $p < .001$, $\eta^2_p = .85$, showed that EP_V increased with increasing tempo (1500 ms: $M = 0.36$ cm, 750 ms: $M = 0.55$ cm, 500 ms: $M = 0.63$ cm, all $p < .05$).The significant TemporalTarget x Tempo interaction, $F(4, 92) = 7.1$, $p < .001$, $\eta^2_p = .24$, showed that in tempo 500 ms EP_V was higher in the presentation condition ($M = 0.7$ cm) than the absence condition and the imagery condition ($M = 0.6$ cm, $M = 0.6$ cm, both $p < .05$). A significant TemporalTarget x GoalType interaction, $F(4, 92) = 8.69$, $p = .002$, $\eta^2_p = .28$, indicated that in the presentation and the imagery condition EP_V was higher in movements towards the combined target (both $M = 0.62$ cm) than towards the single target (both $M = 0.53$ cm, both $p < .05$). Importantly, this was not the case in the absence condition ($p > .05$).

3.2. Discussion

In order to dissociate the role of goal representations and physically present target properties for movement execution towards targets, we compared the kinematics of movements towards temporal targets that were a) actually presented (presentation condition), b) imagined (imagery condition), or c) neither presented nor imagined (absence condition). One temporal target was presented/imagined/absent on one side of the movement, and additionally two spatial targets were visually presented on both sides of the movement. Overall, movement kinematics were similar in the presentation and the imagery conditions: a temporal kinematic pattern (higher PTPV, lower PMT) in movements towards the combined goal in comparison to the side with the single goal was observed. Moreover, movements towards the combined goal showed higher spatial variability (EP_V) in both the presentation and the imagery conditions. The absence condition differed from both the presentation and the imagery conditions: no differences in the shape of the trajectory between movement sides were observed, the kinematic pattern was symmetric, and no difference in spatial variability between movement sides was observed. There were some gradual differences between the presentation and the imagery condition in the shape of the trajectory. PTPV varied more with tempo in the presentation than in the imagery condition. With respect to temporal performance, in the imagery condition RMT was higher than instructed in fast tempo, and in the absence condition RMT was lower than instructed in slow tempo. The presentation condition did not differ from instructed durations. Temporal variability was higher in the imagery condition than in the presentation condition.

In accordance with our hypothesis, the presentation and the imagery conditions showed a similar kinematic pattern, with more pronounced temporal kinematic patterns towards the combined than towards the single goal. This was not the case in the absence condition. Thus, the results are in favor of the assumption that goal representations shape movement kinematics, rather than the mere physical presence or absence of targets. The kinematic pattern observed is in accordance with other studies showing an asymmetric velocity profile for movements directed towards temporal targets (Balasubramaniam, Wing, & Daffertshofer, 2004; Rieger, 2007a; Torre & Balasubramaniam, 2009) as well as for movements directed towards temporal effects (Walter & Rieger, 2012a; Doumas & Wing, 2007; Dahl, 2000), which helps to achieve the timing goals of the task (Torre & Balasubramaniam, 2009). Our results showed that the occurrence of such a kinematic profile is not limited to the physical presence of temporal targets, but also occurs with imagined temporal targets, indicating that goal representations shape the trajectory

Contrary to our expectations we observed a temporal kinematic pattern in all three tempi. We therefore failed to show a change from slow tempo to fast tempo with a spatial kinematic pattern in the former and a temporal kinematic pattern in the latter. This may be due to the use of a medium spatial difficulty (ID = 2.7) in the present experiment in contrast to the study by Rieger (2007a) in which the spatial difficulty was higher (ID = 4.7). It seems that participants could easily meet the spatial accuracy demands of the task even at faster tempi, therefore they did not pay more attention to them when temporal demands are lower (slower speeds).

The general kinematic *pattern* in the presentation and the imagery condition was the same in all three tempi, but PTPV varied less with tempo in the imagery condition than in the other conditions. Thus, the temporal kinematic pattern is less pronounced in the imagery than in the presentation condition. This may be because in the imagery condition the rhythms had to be remembered, and therefore the goal representation relied solely on internal representations with no opportunity to update it based on external events. This might be cognitively demanding. This interpretation is in accordance with previous results showing that effect-directed movements have a less pronounced temporal kinematics pattern than target-directed movements (Walter & Rieger, 2012a), which is attributed to higher cognitive demands in effect-directed movements than in target-directed movements.

The imagery condition had higher temporal variability in all tempi and additionally longer movement times in fast tempo. Higher temporal variability can be explained by the lack of opportunity to update the temporal goal representation and to correct subsequent errors due to external events. As a consequence, imagined temporal targets may be represented less precise than presented targets. Higher movement times in fast tempo may be an attempt to compensate for higher cognitive demands of the task, due to the combined requirement to move fast and to rely on internal representations of a remembered rhythm (for similar findings with effect-directed movements see Walter & Rieger, 2012a). Interestingly, in the absence condition a different pattern than in the imagery condition was observed. Whereas temporal variability did not differ from the presentation condition, movement duration was shorter than instructed in slow tempo, but did not differ from the instructed durations in the other tempi. Thus, whereas the physical presence of a temporal target clearly determines performance its physical absence has a different impact depending on whether an explicit internal representation of a temporal target is formed (as in the imagery condition) or not (as in the absence condition).

To sum up, the kinematic pattern in the imagery condition resembled the kinematic pattern in the presentation condition, but differed from the kinematic pattern in the absence condition. Thus, the representation of targets as goals and not their physical presence shapes movement trajectories. Differences between imagined and presented targets can be attributed to less precise goal representations and higher cognitive demands in the imagery than in the presentation condition.

4. Results and Discussion: One spatial/two temporal targets constellation

4.1. Results

Proportional time to peak velocity (PTPV, see Figure 4.3, upper panel). A significant main effect of Tempo, $F(2, 46) = 55.53$, $p < .001$, $\eta^2_p = .80$, indicated that PTPV was significantly lower in tempo 1500 ms (M = 43.9 %) than in tempo 750 ms (M = 52.1%, $p < .05$), whereas PTPV in tempo 750 ms did not differ significantly from in tempo 500 ms (M = 52.1%, $p > .05$). A significant main effect of GoalType, $F(2, 46) = 75.42$, $p < .001$, $\eta^2_p = .77$, indicated that movements towards the combined goal (M = 47.2 %) had lower PTPV than movements towards the single goal (M = 51.5 %, $p < .05$). These main effects were slightly modified by a significant Tempo x GoalType interaction, $F(4, 92) = 33.56$, $p < .001$, $\eta^2_p = .75$. The difference between the goal sides was significantly higher in tempo 1500 ms (M = -6.8 %) than in tempo 750 ms (M = - 3.9 %, p < .05) and 500 ms (M = - 2.3 %), with the latter also differing significantly from tempo 750 ms ($p < .05$).

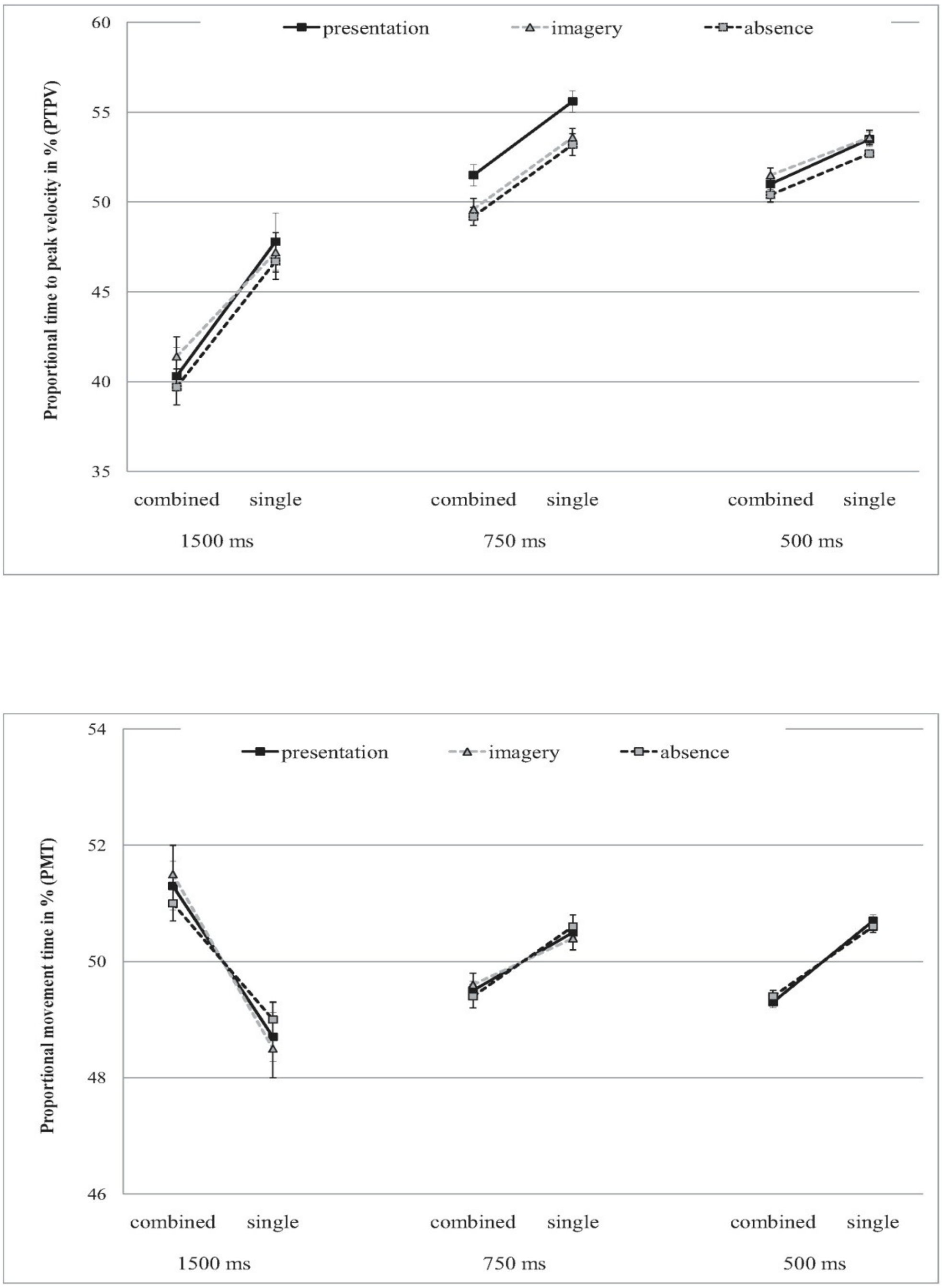


Figure 4.3. One spatial/two temporal targets constellation. Means and standard errors (error bars represent +/- 1 SE) of proportional time to peak velocity in % (PTPV) and proportional movement time in % (PMT), separately for the three temporal target conditions, the three tempi, and the two goal types.

Proportional Movement Time (PMT, see Figure 4.3, lower panel). The significant Tempo x GoalType interaction, $F(4, 92) = 21.02$, $p < .001$, $\eta^2_p = .48$, showed that in tempo 1500 ms PMT was higher in movements towards the combined goal ($M = 51.3$ %) than in movements towards the single goal ($M = 48.7$ %, $p < .05$). In tempo 750 ms and 500 ms PMT was higher in movements towards the single goal ($M = 50.5$ %; $M = 50.7$ %, respectively) than towards the combined goal ($M = 49.5$ %; $M = 49.3$ %, both $p < .05$, respectively).

Reversal Movement Time Variability (RMT_V, see Table 4.2). The main effect of Tempo, $F(2, 46) = 55.53$, $p < .001$, $\eta^2_p = .81$, showed that RMT_V decreased with increasing tempo (1500 ms: $M = 72$ ms; 750 ms: $M = 34$ ms; 500 ms: $M = 21$ ms, all $p < .05$). A significant main effect of TemporalTarget, $F(2, 46) = 3.92$, $p = .027$, $\eta^2_p = .15$, indicated that RMT_V was lower in the presentation condition ($M = 38$ ms) than in the imagery condition ($M = 47$ ms, $p < .05$). The absence condition ($M = 43$ ms) did not differ significantly from either of the other conditions (both $p < .05$).

Table 4.2. Experiment 1. One spatial /two temporal target constellation. Variables describing temporal and spatial performance. Means and standard errors (in parenthesis) of Reversal Movement Time Variability in ms (RMT_V), Reversal Movement Time in ms (RMT), and Endpoint Variability in cm (EP_V), separately for the three temporal target conditions, the three tempi, and the two goal types.

	1500 ms M (SE)		750 ms M (SE)		500 ms M (SE)	
	Single	combined	single	combined	single	combined
Reversal Movement Time Variability in ms (RMT_V)						
presentation	70 (8)	66 (6)	27 (2)	27 (1)	17 (2)	20 (3)
imagery	81 (7)	71 (7)	41 (3)	38 (2)	25 (2)	24 (2)
absence	75 (8)	69 (7)	35 (3)	34 (3)	21 (2)	22 (3)
Reversal Movement Time in ms (RMT)						
Presentation	1471 (9)		747 (3)		498 (6)	
Imagery	1268 (42)		734 (23)		508 (20)	
Absence	1261 (32)		687 (22)		514 (20)	
Endpoint Variability in cm (EP_V)						
presentation	0.31 (0.02)	0.81 (0.03)	0.52 (0.03)	0.90 (0.04)	0.56 (0.02)	0.92 (0.05)
imagery	0.36 (0.03)	0.82 (0.04)	0.49 (0.03)	0.82 (0.04)	0.52 (0.03)	0.83 (0.04)
absence	0.33 (0.02)	0.82 (0.04)	0.53 (0.03)	0.96 (0.06)	0.54 (0.02)	0.92 (0.06)

*Reversal Movement Time (RMT, see Table 4.2).*In tempo 1500 ms RMT was significantly shorter than the instructed duration in all 3 conditions (all $p < .05$). This deviation from the instructed duration was relatively small in the presentation condition and higher in the imagery and the absence condition. Consequently, the presentation condition differed significantly from the imagery ($p < .05$) and the absence condition ($p < .05$). The latter two conditions did not differ significantly from each other ($p > .05$). RMT in the absence condition was also shorter than the instructed duration in tempo 750 ms ($p < .05$).

Endpoint Variability (EP_V, see Table 4 2). A significant main effect of Tempo, $F(2, 46) = 23.05$, $p < .001$, $\eta^2_p = .50$, indicated that movements in tempo 1500 ms (M = 0.58 cm) had lower EP_V than movements in tempo 750 ms and tempo 500 ms (M = 0.70 cm, M = 0.71 cm, both $p < .05$, the latter two tempi did not differ significantly from each other: $p > .05$). A significant main effect of GoalType, $F(1, 23) = 371.18$, $p < .001$, $\eta^2_p = .91$.indicated that movements towards the combined goal (M = 0.46 cm) had lower EP_V than movements towards the single goal (M = 0.87 cm, p < .05).

4.2. Discussion

In the one spatial/two temporal targets constellation, a spatial target was always visually presented on one side of the movement and two temporal targets were additionally presented/imagined/absent on both sides of the movement. All three temporal target conditions showed a similar kinematic pattern. PTPV was lower towards the combined goal in all three tempi, but the difference between both sides decreased with increasing tempo. PMT was higher towards the combined goal than towards the single goal in slow tempo, the reverse was the case in medium and fast tempo. EP_V was lower towards the combined goal and in slow tempo. The imagery condition had higher RMT_V than the presentation condition, whereas RMT_V was intermediate in the absence condition. In all three temporal target conditions RMT was shorter than instructed in slow tempo. In the absence condition RMT was also shorter than instructed in medium tempo. However, the presentation condition deviated less in slow tempo than the imagery and the absence condition.

In contrast to what we expected, we did not obtain differences in the kinematic patterns between the three temporal target conditions. Instead, a switch in movement kinematics occurred in all temporal target conditions. In slow tempo a spatial kinematic pattern (low PTPV, high PMT) towards the combined goal emerged. This was expected for slow tempo (spatial targets can be incorporated more easily) because in the presentation and the imagery conditions the combined goal should have precedence over the single goal, and in the absence condition the single spatial target compared to no target should also lead to this pattern.

In medium and fast tempo however another pattern was found in all temporal target conditions: whereas low PTPV still points to a spatial kinematic pattern, low PMT points to a temporal kinematic pattern. However, with increasing tempo PTPV differences between the combined and single goal decreased. These observations indicate that the pattern starts to change (though a complete switch is not observed in our data) from a spatial to a temporal kinematic pattern towards the combined goal with increasing tempo. Surprisingly, this result for medium and high tempo was also observed in the absence condition. An explanation for this finding might be that in absence condition participants also represent a rhythm consisting of temporal targets at both sides of the reversal movement. The general experimental context and the demonstration phase with the circle moving at a regular pace may have been responsible for this. The regularity of the moving circle may have induced such rhythmical representations. Thus, the goal representations in the three temporal target conditions may have been more similar than intended, resulting in similar kinematic patterns.

Based on this it seems likely that participants also had a representation of temporal goals on both sides of the reversal movement in the two spatial/one temporal target constellation. Indeed, it may even be the default mode of the cognitive-motor system to automatically represent temporal goals when a movement reversal task is performed. This does however not invalidate our interpretation of the results of the two spatial/one temporal target constellation: Participants formed different temporal goal representations in the imagery (one temporal target) and the absence condition (two temporal targets). These different goal representations resulted in different kinematic patterns. Therefore, we still conclude that movement kinematics are shaped by the goal representations.

Regarding temporal performance, again the imagery condition had higher temporal variability than the presentation condition. Temporal variability in the absence condition was intermediate. This indicates that imagined temporal targets are represented less precise than presented targets. This is corroborated by the finding that in slow tempo the presentation condition deviates to a smaller degree from the instructed duration.

To sum up, we did not find differences in movement kinematics between the temporal target conditions in the two spatial/one temporal target constellation. All three conditions showed a spatial kinematics pattern in slow tempo and a mixed pattern in medium and fast tempo. Most likely, participants also represented a regular rhythm in the absence condition.

5. General Discussion

In the present study we investigated the influence of goal representations and the role of the physical presence of targets on movement control. We did this by analyzing how participants execute continuous reversal movements. Participants performed movements towards combinations of presented spatial targets and temporal targets that were presented, imagined or absent. In the two spatial/one temporal target constellation, movements towards presented and imagined temporal targets were executed in a comparable manner and in a different way than movements towards absent targets, indicating that goal representation is more important than the presence of targets. Typical temporal movement kinematics emerged in movements towards a combination of presented spatial targets and presented/imagined temporal targets, which help to accomplish the timing goal of the movement. In the one spatial/two temporal target constellation movements in the presentation, imagery, and absence condition were executed in a similar way. Most likely, participants also represented a rhythm, consisting of temporal targets at both reversals, in the absence condition. However, this does not invalidate our interpretation of the two spatial/one temporal target constellation: Participants formed different temporal goal representations in the imagery and the absence condition, resulting in different kinematic patterns. Results from both goal constellations indicate that goal representation is less precise with imagined than with presented targets, probably because updating and error correction are not possible: Movements towards imagined temporal targets had higher temporal variability, longer movement times in fast tempo (two spatial/one temporal target constellation), shorter movement times in slow tempo (one spatial/two temporal targets constellation), and showed less variation with tempo in proportional time to peak velocity (two spatial/one temporal target constellation) than movements towards presented temporal targets.

Overall the results show that the internal representation of a target and not its presence shapes movement kinematics. This is in accordance with the ideomotor principle of action control. According to the ideomotor theory the anticipation of the intended consequences of a movement guides movement initiation, selection, and execution (Knuf, Aschersleben, & Prinz, 2001; Kunde, 2001, 2003; Kiesel & Hoffmann, 2004; Rieger, 2007b). Whereas traditionally movement kinematics towards targets are thought to reflect physical properties of those targets, the here presented data indicate that they rather reflect the internal representation of those targets. Consequently, movement kinematics towards presented and imagined targets are very similar and reflect means to attain the intended goal of the movement most adequately. Goal representations are present before the movement is actually executed and influence movement execution by evoking event anticipations, as the ideomotor theory assumes. These theoretical claims have found broad evidence for movement initiation (Kunde, 2001; 2003; Kiesel & Hoffmann, 2003) and selection (Knuf et al, Rieger, 2007b). Here we provide evidence that event anticipations also influence movement execution (see also Kunde, 2004). Further, the present data provide evidence that the ideomotor theory can be applied to target-directed movements (see also Walter & Rieger, 2012a, b), whereas most previous studies investigated effect-directed movements. Movement kinematics towards imagined temporal targets have rarely been systematically compared to movements towards presented temporal targets. In studies on sensory-motor synchronization participants sometimes have to continue tapping in an isochronous rhythm after they have synchronized their taps with a presented rhythm (for a review see Repp, 2005). In contrast to our study in such a continuation phase participants are usually not instructed to vividly imagine the tones of that rhythm and to synchronize their taps with those imagined tones, but they are rather instructed just to continue tapping. Another difference of such tasks to our study is that the continuation phase always follows the synchronization phase.

Differences between movements towards presented and imagined targets indicated that imagined temporal targets are represented less precise, probably due to the lack of opportunity to update and correct errors in the representation. It is not clear whether such an imprecision would also be observed in everyday life situations. At least in familiar situations, for example when dancing to an imagined but known song this might not be the case. Results on auditory imagery (for a review see Hubbard, 2010) are contradictory. On the one hand, they indicate that in auditory imagery timing aspects of the images are preserved. For example, the time required to scan across an imagined melody depends on the number of beats (Halpern & Zatorre, 1999), and the image of a specific melody seems to contain its tempo (Halpern, 1988, see also Zatorre & Halpern, 2005). On the other hand, consistent with our findings, other results indicate that temporal acuity is less precise in auditory imagery than in auditory perception (Janata & Paroo, 2006). Interestingly, it has been pointed out that auditory imagery involves expectancies (e.g. Kraemer, Macrae, Green, & Kelley, 2005; Meyer, Elmer, Baumann, & Jancke, 2007). Such expectancies allow the generation of perceptual representations when no actual input is available (Janata, 2001). Evidence for expectancies in auditory imagery is in line with our argumentation that imagined temporal targets function as action goals which influence performance by the anticipation of their intended perceptual consequences.

To conclude, the representation of targets as temporal goals, rather than their physical characteristics, shapes movement trajectories. Thus, movement control in target-directed actions relies on goal representations as ideomotor theory of action control suggests. However, the actual presence of targets plays an important role for the precision of movements.

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List of Abbreviations

A	Asynchronies
ANOVA	Analysis of Variance
Dist_X	Movement Distance on the x-axis
eID	empirical Index of Difficulty
EP_V	Endpoint Variability
ID	Index of Difficulty
MA	Movement Amplitude on the x-axis
MT	Movement Time
PMT	Proportional Movement Time
PTPV	Proportional Time to Peak Velocity
R_MTV	Reversal Movement Time Variability
RMT	Reversal Movement Time
TEC	Theory of Event Coding

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SELBSTSTÄNDIGKEITSERKLÄRUNG

Hiermit erkläre ich, dass die vorliegende Arbeit ohne unzulässige Hilfe und ohne Benutzung anderer als der angegebenen Hilfsmittel angefertigt wurde und dass die aus fremden Quellen direkt oder indirekt übernommenen Gedanken in der Arbeit als solche erkenntlich gemacht worden sind.

Andrea M. Walter

Leipzig, den 21. Mai 2013

BIBLIOGRAPHIC DETAILS

Walter, Andrea Michaela

The role of goal representations in action control

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Dissertation

199 pages, 100 references (chapter 1), 15 figures, 10 tables

Actions are goal-directed. It can be the goal of an action to change the environment (i.e. to produce an effect), but also to change one´s own situation in the environment (i.e. to move to a physical target). Previous research has shown that kinematics of actions directed towards physical targets are not only mere reactions to such targets. Instead, targets evoke intentional goals. Representations of such intentional goals influence action execution. However, thus far, most studies in the context of the ideomotor theory of action control have focused on the influence of anticipated action effects on action planning. The role of targets as action goals as well as the role of goal anticipations on overt action execution has mostly been neglected.

In this dissertation the role of goal representations in action control was investigated. The ideomotor theory served as a theoretical framework. It was assumed that targets function as action goals similar to action effects and that action goals influence action execution by the anticipation of upcoming events. Action execution towards targets and towards effects was compared. This was done in the temporal and the spatial domain. Furthermore, goal representations were manipulated in order to evaluate their influence on action execution and to disentangle the role of physical target characteristics and the role of goal representations.

The findings obtained strengthen the assumption that goal representations play an important role in action control. First, both targets and effects can be viewed as goals of an action in the temporal and spatial domain. Second, movement kinematics are shaped by the way targets are represented as action goals, rather than by physically target properties. In conclusion, as goal representations are formed *before* the action is actually executed they influence action execution by the anticipation of upcoming events. The ideomotor theory of action control should incorporate action targets as goals similar to action effects.

Paper/Zusammenfassung

Introduction

What differentiates an action from pure movement is that an action is directed towards a certain goal. It can be the goal of an action to to change the environment (i.e. to produce an effect), but also to change one´s own situation in the environment (i.e. to move to a physical target). An important theoretical approach in the field of action research is the ideomotor theory of action control (James, 1890/1981; Prinz, 1997). It states first that an action becomes connected with its sensory consequences due to contingent appearance of both ("learning principle", Prinz, 2012). Second, it assumes that such associations can be used in the following to plan and execute an action by the anticipation of its perceptual consequences ("performance principle", Prinz, 1997, 2012). The claims of the ideomotor theory of action control have found broad empirical evidence for both the learning (e.g. Elsner & Hommel, 2001, 2004; Hommel, Alonso, & Fuentes, 2003) and the performance principle (e.g. Knuf, Aschersleben, & Prinz, 2001; Kunde, 2001, 2003). Thus far, the majority of studies have focused on the influence of anticipated action effects (the production of changes in the environment) on the action planning phase preceding the overt action execution phase. The role of targets as action goals as well as the role of goal anticipations on the overt action execution phase has mostly been neglected so far.

An exception points to the need to take targets as action goals similar to action effects into account. It has been shown that kinematics of actions directed towards physical targets cannot only be viewed as mere reactions to those targets (Rieger, 2007). Instead, they evoke intentional goals such as "to be at a certain place at a certain point in time". It is the representation of such intentional goals that influences action execution. Further, it has been shown that effect anticipations also affect action execution (Kunde, Koch & Hoffmann, 2004).

The **main focus** of this dissertation was to investigate the role of goal representations in action control. It is assumed that it can be the goal of an action to produce an effect, but also to move towards a physical target. In line with the ideomotor theory action goals should pose an influence on action execution by the anticipation of upcoming events. Specifically, actions towards targets and towards effects were examined and compared in both the temporal (Study 1) and the spatial (Study 2) domain. Furthermore, goal representations were directly manipulated in order to evaluate their influence on action execution (Study 3).

Summary of the dissertation

In all three studies participants performed continuous-reversal movements (on the medial-lateral axis) on a writing pad towards temporal (tones) and spatial (boxes) goals, -or a combination of both. Visual feedback of the current movement position and spatial goals were presented on a computer screen. Temporal goals were acoustically presented through loudspeakers. The following variables describing the kinematic curvature were analyzed: a) the time to reach peak velocity relative to the complete duration of the movement (proportional time to peak velocity in %, PTPV), and b) the time spent on one movement relative to the time spent on the complete reversal movement (proportional movement time in %, PMT). Kinematic patterns were compared in order to evaluate the underlying mechanisms of action control. A typical *spatial* kinematics pattern is characterized by relative high PMT and low PTPV, and a typical *temporal* kinematic pattern is characterized by relative low PMT and high PTPV. Both patterns are suited to achieve the intended goal of an action most optimally (Rieger, 2007). In addition, several variables describing temporal and spatial accuracy were analyzed.

The **first main question** was whether actions directed towards self-produced effects and towards presented physical targets have similar underlying mechanisms of action control. It was assumed that this should be the case as both can be viewed as goals of an action influencing action execution by the anticipation of upcoming events. In the case of effects the goal of the action is the production of the effect itself and in the case of targets the goal is “to be at a certain place/time”. On the other hand there are also some differences between targets and effects that could result in differences in the observed kinematics. Targets are externally generated and are usually present in the environment irrespective of what a person does. In contrast, effects are internally generated and therefore depend on a person´s action. Consequently, targets provide more precise temporal/spatial information, while memory processes are more important in effect-directed actions (for example, a location has to be remembered in spatial action effects).

S**tudy 1** (Walter & Rieger, 2012a) aimed at investigating whether underlying principles of action control are similar in target-directed and effect-directed actions in the temporal domain. In three experiments participants either synchronized movement reversals with regularly presented tones (temporal targets), or produced tones themselves at reversals isochronously (temporal effects). Target-directed and effect-directed actions were compared across conditions in different goal sets with varying goal features (Experiment 1), integrated in one condition (Experiment 2), or compared across conditions with additional spatial demands (Experiment 3). S**tudy 2** (Walter & Rieger, 2012b) asked whether target-directed and effect-directed actions are controlled in a comparable manner in the spatial domain. In two experiments participants either had to reverse their movements within black boxes that were constantly present (spatial targets) or had to produce black boxes at movement reversals (spatial effects). Target-directed and effect-directed actions were compared across conditions in sets with different goal characteristics (Experiment 1). To further investigate differences between them they were integrated within one condition (Experiment 2).

Results of both studies showed consistently that movement kinematics of target- and effect-directed actions were very similar in the temporal (Study 1) and the spatial (Study 2) domain. This indicates that both types of actions are controlled in a similar way, including the anticipation of upcoming events. Similar kinematic patterns were observed in a variety of experimental manipulations. In **Study 1** both types of action showed a typical *temporal* kinematic pattern and an irrelevant goal characteristic (i.e. loudness) was integrated in the representation in both cases. When targets and effects were integrated within the same reversal movement, similarities were enhanced, and even when the task posed spatial demands in addition to temporal demands, target- and effect-directed actions were executed in a very similar way. Moreover, similar timing mechanisms were demonstrated. In **Study 2** target-directed and effect-directed actions had a typical *spatial* kinematic pattern. Linear functions as suggested by Fitts´ Law (Fitts, 1954) described the relation between movement time and spatial accuracy in both cases. Only gradual differences between the kinematic patterns were observed in both studies. They were attributed to higher cognitive demands of effects, which are assumed consequently to be represented less precisely than targets.

The **second main question** was to find further evidence for the assumption that action execution is influenced by goal representations (referred to as goal representation hypothesis) rather than by physical target characteristics. **Study 3** (Walter & Rieger, in preparation) aimed at disentangling the role of physical target characteristics and the role of goal representations. Goal representations were directly manipulated via the given instructions, while physical target characteristics of the experimental situation were kept constant. Temporal targets were either acoustically presented (present), participants were instructed to imagine them (imagined), or neither presented nor imagined (absent). Visual-spatial targets were always presented. Consequently, goal representations of present and imagined targets should be similar, even though they differ in their physical characteristics. In contrast, goal representations of imagined and absent targets should differ, even though their physical characteristics are the same. If the goal representation hypothesis holds kinematics towards present and imagined targets should be similar, but differ from those towards absent targets.

Results of **Study 3** showed that kinematics of actions towards present and imagined targets are similar, whereas they differed from kinematics towards absent targets when a temporal target existed on one side of the reversal movement but not the other. The results indicated that the representation of targets as temporal goals, rather than physical target characteristics shapes movement kinematics in a specific manner. When a temporal target existed on both sides of the reversals no differences in the kinematic pattern between movements towards present, imagined and absent targets were obtained indicating that participants may automatically form temporal goal representations in continuous reversal movements. Further, it was shown that imagined targets are represented less precise than presented targets.

Conclusions

This dissertation investigated the role of goal representations in action control. It aimed at clarifying how different action goals are represented and how these internal goal representations influence action execution. This was done by analyzing *how* participants execute simple, intentional actions. In comparison to existing work, the current studies focused on action execution in the light of the ideomotor theory of action control and viewed targets as action goals similar to effects. Taken together, the results strengthen the assumption that both targets and effects can be viewed as goals of an action in the temporal and spatial domain. They have similar mechanisms of action control, including the anticipation of upcoming events. Thus, ideomotor theory of action control should incorporate action targets as goals similar to action effects. Moreover, movement kinematics are shaped by the way targets are represented as action goals, rather than by physically target properties. As these goal representations are being formed *before* the action is actually executed and then pose an influence on the action execution phase this is in accordance with ideomotor theory of action control.

Allgemeine Einleitung

Eine „Handlung“ hebt sich von bloßer „Bewegung“ dadurch ab, dass sie auf das Erreichen eines Zieles („goal“ im folgenden als Handlungsziel bezeichnet) gerichtet ist. Das Handlungsziel kann in einer Veränderung der Situation des Individuums in seiner Umwelt (Bewegung zu einem physischen Ziel, „target“) oder in einer Veränderung der Umwelt (Erzeugen eines Effektes) bestehen. Ein wichtiger theoretischer Ansatz der Handlungsforschung ist das ideomotorische Prinzip (James, 1890/1981; Prinz, 1997). Ideomotorische Theorien gehen erstens davon aus, dass eine Handlung mit den sensorischen Konsequenzen assoziiert wird, die üblicherweise bei ihrer Ausführung auftreten („Lernprinzip“, Prinz, 2012). Zweitens gehen sie davon aus, dass solche Assoziationen dazu benutzt werden können, eine Handlung zu planen und auszuführen. Dies geschieht, indem ihre sensorischen Konsequenzen vorher mental vorgestellt (antizipiert) werden („Ausführungsprinzip“, Prinz, 1997, 2012). Beide Annahmen konnten in zahlreichen empirischen Untersuchungen bestätigt werden: dies gilt sowohl für das „Lernprinzip“ (z.B. Elsner & Hommel, 2001, 2004; Hommel, Alonso, & Fuentes, 2003), als auch für das „Ausführungsprinzip“ (z.B. Knuf, Aschersleben, & Prinz, 2001; Kunde, 2001, 2003). Bislang wurde in diesem Kontext im Wesentlichen die Rolle von antizipierten Handlungseffekten (Erzeugen eines Effekts in der Umgebung) für die Phase der Handlungsvorbereitung (die der beobachtbaren Handlungsausführung vorangeht) untersucht. Die Rolle von physischen Zielen für die Handlungsausführung stellt ein kaum untersuchtes Thema dar.

Dabei deuten einige Befunde auf eine erhebliche Bedeutung von physischen Zielen für die Handlungsausführung hin, die der von Handlungseffekten gleicht. So konnte gezeigt werden, dass die Kinematik (raumzeitliche Eigenschaften) von Bewegungen zu physischen Zielen nicht als Reaktion auf diese physischen Ziele zu verstehen ist (Rieger, 2007). Stattdessen werden durch physische Ziele intentionale Ziele wie „an einer bestimmten Position zu einem gegebenem Zeitpunkt sein“ aktiviert. Diese Repräsentationen der intentionalen Ziele bestimmen die Steuerung der Handlungsausführung. Weiterhin konnte gezeigt werden, dass antizipierte

Handlungseffekte auch einen Einfluss auf die Phase der Handlungsausführung haben, und nicht nur auf Handlungsplanung und Initiierung (Kunde, Koch & Hoffmann, 2004).

Hauptanliegen der vorliegenden Dissertation war es, die Rolle von Zielrepräsentationen für die Handlungssteuerung zu untersuchen. Dabei wurde davon ausgegangen, dass es sowohl ein Handlungsziel sein kann, einen Effekt zu erzeugen, als auch, sich zu einem physischen Ziel zu bewegen. Im Sinne ideomotorischer Theorien wurde angenommen, dass antizipierte Handlungsziele die Phase der beobachtbaren Handlungsausführung beeinflussen. Konkret wurden Handlungen, die auf die Erzeugung eines Effekts gerichtet sind und solche, die auf das Erreichen eines physischen Zieles gerichtet sind, untersucht und verglichen. Im Folgenden wird hier die Rede von Effektbewegungen und Zielbewegungen sein. Dies geschah sowohl für Handlungen in der zeitlichen, als auch in der räumlichen Domäne. Außerdem wurden Zielrepräsentationen direkt manipuliert, um zu klären, welchen Einfluss sie auf die Handlungssteuerung haben.

Zusammenfassung der Dissertation

In allen drei Studien führten Probanden auf einem Grafiktablett Umkehrbewegungen (entlang der medial-lateralen Achse) zu zeitlichen (Töne) und räumlichen (Kästen) Handlungszielen, bzw. Zielkombinationen aus. Visuelle Rückmeldung über die Bewegung und räumliche Ziele wurden auf einem Bildschirm dargeboten. Zeitliche Ziele wurden über Lautsprecher präsentiert. Um die Bewegungskinematik zu beschreiben wurden a) die proportionale Zeit zur Maximalgeschwindigkeit (PTPV, proportional time to peak velocity, Zeitpunkt zu dem die Maximalgeschwindigkeit auftritt relativ zur Gesamtzeit einer Bewegung) und b) die proportionale Bewegungszeit (PMT, proportional movement time, Zeit die auf eine Hälfte der Umkehrbewegung relativ zur Gesamtzeit der Umkehrbewegung verwendet wird) analysiert. Kinematische Muster wurden verglichen, um Rückschlüsse auf die zugrunde liegenden Mechanismen der Handlungssteuerung ziehen zu können. Geringere PTPV und höhere PMT kennzeichnen eine stärker ausgeprägte *räumliche* Zielkinematik, wohingegen hohe PTPV und relativ niedrige PMT eine stärker ausgeprägte *zeitliche* Zielkinematik kennzeichnen. Die beiden kinematischen Muster beinhalten Charakteristiken, die es ermöglichen, den Handlungszielen möglichst optimal gerecht zu werden (Rieger, 2007). Zusätzlich wurden Variablen analysiert, die die zeitliche und räumliche Variabilität beschreiben.

Das **erste Hauptanliegen** war es herauszufinden, ob bei Ziel- und Effektbewegungen gleiche Mechanismen der Handlungssteuerung eine Rolle spielen. Es wurde angenommen, dass dies der Fall sein sollte, da sie beide Handlungsziele darstellen, die die Handlungsausführung über ihre Antizipation beeinflussen. Im Falle von Effekten ist das Handlungsziel die Veränderung der Umwelt und im Falle von physischen Zielen „an einer bestimmten Position zu einem gegebenem Zeitpunkt sein“. Auf der anderen Seite unterscheiden sie sich auch in einigen Aspekten, die zu einer unterschiedlichen Kinematik führen könnten. Ziele sind extern generiert und normalerweise in der Umgebung unabhängig von den Handlungen einer Person vorhanden. Dagegen sind Effekte selbst generiert und hängen deswegen von den Handlungen einer Person ab. Entsprechend stellen Ziele präzisere zeitliche/räumliche Informationen für eine Handlung bereit, wohingegen bei Effekten Gedächtnisprozesse (z.B. muss bei räumlichen Handlungseffekten ein Ort erinnert werden) in stärkerem Ausmaß eine Rolle spielen.

Studie 1 (Walter & Rieger, 2012a) der vorliegenden Dissertation untersuchte, ob die Handlungsausführung bei gegebenen zeitlichen Zielen ähnlich gesteuert wird wie bei selbst produzierten zeitlichen Effekten. In drei Experimenten wurde wurden die Probanden gebeten, die Umkehrpunkte ihrer Bewegungen entweder mit Tönen zu synchronisieren, die in einem bestimmten isochronem Rhythmus präsentiert wurden (zeitliche Zielbedingung) oder die Töne selbst isochron an den Umkehrpunkten der Bewegung zu erzeugen (zeitliche Effektbedingung). In Experiment 1 wurden beide Handlungsarten über die Bedingungen hinweg in mehreren Ziel/Effektkonstellationen verglichen, die sich in ihren Zieleigenschaften unterschieden. In Experiment 2 wurden Ziel- und Effektbewegungen in eine Bedingung integriert. In Experiment 3 wurden zeitliche und räumliche Ziele in einer Bedingung kombiniert. **Studie 2** (Walter & Rieger, 2012b) hatte zum Ziel, die Handlungsausführung zu gegebenen räumlichen Zielen mit der zu selbstproduzierten räumlichen Effekten zu vergleichen. In zwei Experimenten wurden räumliche Ziele entweder durchgehend präsentiert (räumliche Zielbedingung) oder von den Probanden selbst an den Umkehrpunkten der Bewegung erzeugt (räumliche Effektbedingung). In Bedingungen mit räumlichen Zielen wurden diese durchgehend präsentiert. Räumliche Effekte erschienen für kurze Zeit, sobald die Probanden den Umkehrpunkt einer Bewegung erreicht hatten. In Experiment 1 wurden Ziel- und Effektbewegungen in verschiedenen Konstellationen, die sich in ihren Zielcharakteristiken unterschieden verglichen. Um Unterschiede zwischen den beiden Handlungsarten genauer zu untersuchen wurden in Experiment 2 beide in einer Bedingung intergiert.

Die **Ergebnisse** beider Studien zeigten übereinstimmend, dass sich die Kinematik von Ziel- und Effektbewegungen sowohl in der zeitlichen (Studie 1), als auch in der räumlichen (Studie 2) Domäne sehr ähnelt. Hieraus kann geschlossen werden, dass bei beiden Handlungen gleiche Mechanismen der Handlungssteuerung eine Rolle spielen, inklusive antizipierter Handlungsziele. Ähnliche kinematische Muster wurden in zahlreichen experimentellen Manipulationen beobachtet. In **Studie 1** zeigten sowohl Ziel- als auch Effektbewegungen ein typisch *zeitliches* kinematisches Muster. Eine irrelevante Zielcharakteristik (Lautstärke) wurde in beiden Fällen in die Zielrepräsentation integriert. Wenn Ziele und Effekte innerhalb der gleichen Umkehrbewegungen präsentiert wurden, verstärkte sich ihre Ähnlichkeit. Sogar wenn die Aufgabe zusätzliche räumliche Anforderungen stellte, wurden Ziel- und Effektbewegungen auf sehr ähnliche Art ausgeführt. Darüber hinaus konnte gezeigt werden, dass beide Arten von Bewegungen eine gemeinsame Quelle zeitlicher Variabilität haben. In **Studie 2** zeigten sowohl Ziel- als auch Effektbewegungen ein typisch *räumliches* kinematisches Muster und konnten mit einer linearen Fitts´ Funktion (Fitts, 1954) beschrieben werden. Ziel- und Effektbewegungen zeigten nur graduelle Unterschiede in beiden Studien. Diese Unterschiede wurden mit höheren kognitiven Anforderungen bei Effekten erklärt, die folglich weniger präzise repräsentiert wurden als physische Ziele.

Das **zweite Hauptanliegen** der vorliegenden Dissertation war es die Hypothese, dass Bewegungen von der Repräsentation von Handlungszielen und nicht von den physischen Eigenschaften dieser Ziele abhängen (Zielrepräsentationshypothese) zu untersuchen. **Studie 3** (Walter & Rieger, in Vorbereitung) sollte die Rollen von physischen Zieleigenschaften und Zielrepräsentationen für die Handlungssteuerung dissoziieren. Dafür wurden die physischen Eigenschaften von Zielen im experimentellen Kontext konstant gehalten, während die Zielrepräsentationen über eine Instruktion manipuliert wurden. Zeitliche Ziele (Töne) wurden entweder tatsächlich präsentiert (Präsentationsbedingung), die Probanden wurden instruiert sich diese vorzustellen (Vorstellungsbedingung), oder nicht präsentiert (Abwesenheitsbedingung). Räumliche Ziele wurden durchgängig präsentiert. Folglich waren die Zielrepräsentationen von in der Präsentations- und der Vorstellungsbedingung gleich, obwohl sie sich in ihren physischen Eigenschaften unterschieden. Andersherum unterschieden sich die Zielrepräsentationen in der Vorstellungs- und Abwesenheitsbedingung, wohingegen ihre physischen Eigenschaften gleich waren. Unter Gültigkeit der Zielrepräsentationshypothese wurde angenommen, dass sich die Kinematik von Bewegungen in der Präsentations- und der Vorstellungsbedingung ähneln sollte, wohingegen sie sich von der Kinematik in der Abwesenheitsbedingung unterscheiden sollte.

Die **Ergebnisse** von **Studie 3** zeigten, dass Bewegungen zu vorgestellten zeitlichen Zielen ähnlich ausgeführt wurden, wie Bewegungen zu tatsächlichen zeitlichen Zielen, nicht jedoch wie Bewegungen zu abwesenden zeitlichen Zielen. Dies war der Fall, wenn ein zeitliches Ziel auf einer Seite der Umkehrbewegung vorhanden war, aber nicht auf der anderen. Die Ergebnisse zeigten, dass die Bewegungsausführung vorwiegend durch Zielrepräsentationen und nicht durch physische Zieleigenschaften beeinflusst wird. Wenn ein zeitliches Ziel auf beiden Seiten der Umkehrbewegung vorhanden war, ähnelten sich die kinematischen Muster zu tatsächlichen, vorgestellten und abwesenden Zielen. Dies deutete darauf hin, dass die Probanden bei kontinuierlichen Umkehrbewegungen automatisch zeitliche Zielrepräsentationen bilden. Außerdem wurde gezeigt, dass vorgestellte Ziele weniger präzise repräsentiert wurden als tatsächliche Ziele.

Schlussfolgerungen

Die vorliegende Dissertation beschäftigte sich mit der Rolle von Zielrepräsentationen in der Handlungssteuerung. Es wurde untersucht, wie verschiedene Handlungsziele repräsentiert werden und wie diese Zielrepräsentationen die Handlungsausführung beeinflussen. Dies geschah, indem analysiert wurde *wie* Probanden einfache intentionale Handlungen ausführten. Im Vergleich zu dem überwiegenden Teil der bisherigen Studien konzentrierten sich die vorliegenden Studien auf die Handlungsausführung im Licht ideomotorischer Theorien und interpretierten dabei auch physische Ziele als Handlungsziele genauso wie Effekte. Zusammengenommen erhärten die Ergebnisse die Annahme, dass sowohl physische Ziele als auch Effekte in der zeitlichen und räumlichen Domäne als Handlungsziele fungieren. Ideomotorische Theorien sollten entsprechend erweitert werden. Weiterhin kann gezeigt werden, dass dieselben Mechanismen der Handlungssteuerung, inklusive der Antizipation von Zielzuständen bei Ziel- und Effektbewegungen eine Rolle spielen. Außerdem wird die Kinematik durch Zielrepräsentationen und nicht durch physische Zieleigenschaften beeinflusst. Da diese Zielrepräsentationen gebildet werden *bevor* die eigentliche Bewegung tatsächlich ausgeführt wird und dann die Bewegungsausführung beeinflussen, entspricht dies den Vorhersagen ideomotorischer Theorien der Handlungskontrolle.

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Confirmation of contribution of co-authors

<u>*Title:*</u> Target- and effect-directed actions towards temporal goals: Similar mechanisms?

<u>*Journal:*</u> *Journal of Experimental Psychology: Human Perception and Performance*

<u>*Authors:*</u> Walter, Andrea M.; Rieger, Martina

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- Experimental setup and preparation of experimental stimuli
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Confirmation of contribution of co-authors

Title: Similar mechanisms of movement control in target- and effect directed actions towards spatial goals?

Journal: *Frontiers in Psychology*

Authors: Walter, Andrea M.; Rieger, Martina

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SELBSTSTÄNDIGKEITSERKLÄRUNG zum monographischen Kapitel

Hiermit erkläre ich, dass ich das monographische Kapitel vier ohne unzulässige Hilfe und ohne Benutzung anderer als der angegebenen Hilfsmittel angefertigt wurde und dass die aus fremden Quellen direkt oder indirekt übernommenen Gedanken in der Arbeit als solche erkenntlich gemacht worden sind.

Andrea M. Walter

Leipzig, den 21. Mai 2013