The role of action effects with movement sequences

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Submitted: august 2013

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Abstract

Based on the theory of event coding (TEC), the present paper presents two experiments that explore the possibility whether or not an action effect can become associated with the representation assumed to underlie a familiar movement sequence, that is, a motor chunk. Both experiments used four 4-key sequences, of which two sequences started with the same stimulus, the other two with another stimulus. In addition, each sequence had a specific response tone presented immediately after the first correct response. In the test phase, the tone was either mapped to the same sequences as was practiced, or had been changed to another sequence that started with the same stimulus. Experiment 1 suggested that participants formed a single response and one motor chunk per sequence . Experiment 2 also consisted of four different sequences but had participants perform only two at the same time and confirmed that an action effect can become associated with a motor chunk, although this association is not robust.

Introduction

The theory of event coding (TEC) is an information processing framework that tries to explain how representations of perceived and/or produced events are cognitively represented and how these representations interact with general perception (Hommel, 2009). As with other ideomotor approaches, the theory asserts that actions are represented in sensory format (Elsner & Hommel, 2001).

According to TEC, cognitive representations of events, such as perceiving and action planning are alternative ways of saying the same thing, namely internally representing the external events (Hommel, Müsseler, Aschersleben, & Prinz, 2001). External events consist of distal feature codes that may contain information about spatial orientation, color, pitch, size, movement etc. Basically, distal feature codes can be thought of as stimuli defining the object and/or event in the environment. For example, consider a person reaching for a cup in front of her. A successful response would mean that numerous features of stimuli and action plan match. Thus, the intended traveling distance and the direction of movement need to match the spatially perceived location of the cup, as well as the intended grip that need to match the perceived size of the cup. According to TEC this is easy because action planning mostly involves specifying and integrating codes representing the intended action, and since these codes have already been activated by perceiving the stimulus, there is not much more to be done (Hommel et al., 2001).

The event codes, which consist of distal features of an event, are central in TEC. Distal feature codes can provide information from many sensory channels, and although they rely on proximal information, they are not restricted to a particular sensory channel. Feature codes however, are not static but evolve throughout experience and are subject to task specifics and intentions. For example, a color may not always be coded as *red*, but we learn to discriminate between *crimson* and *orange* if the situation demands. The same applies to orientation. Take for example *left*. It does not necessarily have to be coded as *left*, but can be *left* in comparison to something else (e.g. Left of the body). As a result, single feature codes may become differentiated into a larger number of codes and can therefore have a vast network of associations (see Hommel et al., 2001 for a more detailed review). These associations become dominant when one is to act upon it. If, for example, two events share a common feature code, it means that both events are activated (ready to be executed). However, the agent decides which event to produce by intentions/goals, thereby reducing the activation of the other event (Hommel et al, 2001). For example, if one is to respond to a stimulus that is presented on the left side of the visual field, the response will be faster when the response is made with the corresponding hand. This is because there are more features in common within this action, as compared to responding with the opposite hand.

As mentioned above, TEC states that voluntary actions spawn by anticipating their distal effects. That means that action control is anticipatory, that is, regulated by representations of intended action effects. Basically, an action effect is a bidirectional association that is formed by the agent between movement of their body (action) and the co-occurrence of the perceivable outcome (effect). And because these associations are bidirectional, sensory effects also allow the agent to recruit motor codes due to the repeatedly co-occurrence.

Although there is ample evidence supporting the claims of TEC regarding actions effects, the focus in the TEC literature has always been on relative simple actions (single-key presses). For example, Hommel (1996) had participants perform in a choice RT task. In this task, a specific tone was presented to a specific response in the acquisition phase. When, in the subsequent test phase, the tones were presented simultaneously with the imperative stimulus, performance declined when the mapping of the tones and stimuli were reversed. Similar results were found when children of age 4 and 7 were exposed to arbitrary sound effects in a choice RT task. Again performance declined when the sound effects were reversed and used as imperative stimuli (Eenshuistra, Weidema, & Hommel, 2004; cf. Eenshuistra, Verschoor, Kray, & Hommel, 2009; Kray, Eenshuistra, Kerstner, Weidema, & Hommel, 2006).

The present study draws on earlier work done by Stöcker and Hoffmann (2004). They have shown that auditory stimuli enhance the development of a sequence representation with a serial reaction time task (SRT), regardless of whether the sound was task relevant or not. In such task, participants respond to one visual stimulus by pressing a key that is usually spatially compatible to that of the stimulus location. Each correct response triggers the presentation of the next stimulus. With practice, reaction times (RTs) decrease when the stimulus sequence is structured but increase when this structure is removed. In Stöcker and Hoffmann (2004) design, experimental conditions differentiated between the visual stimuli and response effects (with or without sound presentation after response execution). In the subsequent test phase participants, who were subjected to auditory stimuli, outperformed those who did not, in both mean interresponse time and sequence initiation (Stöcker & Hoffmann, 2004; Hoffmann, Sebald & Stöcker, 2001). These results indicate that tone effects can become integrated into more complex sequence representations. That is in line with TEC and the ideomotor principle/learning mechanisms proposed by Greenwald (1970) that response effects can become associated with the responses that generate them.

In a similar vein, Keller and Koch (2004) had participants perform a sequence of three key presses by responding to vertically aligned stimuli. In their design, each individual response was linked to a tone that was either matched or mismatched between spatial height and pitch tone. They found that matched key-to-tone-mapping resulted in shorter RTs than the condition that was mismatched. This could be explained by TEC because the code activation threshold, which triggers the associated motor response, is reached sooner when proximal- and distal effects share common features. Similar results have been found in studies concerning tactile pressure and audio loudness (Kunde, 2001; Kunde, Koch, & Hoffmann, 2004), and even rhythm (Keller & Koch, 2006). Note however, that the changes due to the action effects in serial learning tasks only occurred when the tone was used as a response effect (Stöcker & Hoffmann, 2004; Stöcker, Hoffmann & Sebald, 2003).

Little research has been done beyond the scope of the previously mentioned examples. But TEC does not rule out that higher order event codes (i.e. an integration of multiple single event-codes) induce the same effect. Within the domain of discrete sequence production (DSP) task (e.g., Verwey, 1999) there has been evidence that repeatedly executing (single) movement sequences induces content-specific representations in our memory. These are called *motor chunks* (e.g., Brown & Carr, 1989; Lashley, 1951; van Mier & Hulstijn, 1993; Miller, Galanter, & Pribram, 1960; Panzer et al., 2009; Verwey, 1994). Motor chunks, can be selected and executed as if they were a single response (Verwey, 1996, 2001).

The DSP-task is characterized by responding to a relatively small number of stimuli in fixed order. With practice, the first stimulus acts as imperative stimulus for the entire sequence and the remaining key-dependent cues are no longer needed (Verwey, 1999). This seems to be in accordance with TEC's line of reasoning because it asserts that the coding of stimuli is built on feature codes that represent the function of an event. That is, an integration of multiple elements into one meaningful event too. According to TEC (Hommel et al. 2001), any kind of sensory event that repeatedly follows action may become an action effect. It is this association the present study tries to uncover. To be more specific, the present study tries to extend the TEC literature by exploring the possibility that an action effect can become integrated within higher order event codes. Thus, can an action effect become associated with an entire motor chunk?

Experiment I

The first experiment should be seen as an explorative experiment that builds on an unpublished study by Mommer (2011) that tried to improve the insight given by earlier studies with regards to action effects and higher order event codes. Here, an action effect was sought by extending the design of Elsner and Hommel (2001). In Mommer's study (2011), participants executed a single key press with a tone as a response effect (as with Elsner & Hommel, 2001), and a 4-key sequence, that also used a tone as a response effect. In the acquisition phase, he manipulated the onset of the auditory stimulus in the 4-key sequence so that one group of participants heard the tone immediately after the first response (R1) of the sequence and the other group after completion of the entire sequence (R4). The subsequent test phase had two conditions, namely, a congruent- and an incongruent condition. Here, the tone was used as an imperative stimulus and the tone either corresponded with the same sequence that was used in the acquisition phase (congruent condition), or with the other sequence (incongruent condition).

Analysis revealed a replication of the Elsner and Hommel (2001; Exp. 1) findings for the single key presses, namely, faster responses were made in the congruent condition. For the 4-key sequences, it was expected that, if the 4 individual elements of the sequence are indeed represented as a single unit, it is this motor chunk that will be primed (Verwey, 1996). Therefore, the moment of tone presentation in the acquisition phase would be equally effective in terms of response execution in the test phase. Although similar results were found as with the single key (i.e. faster responses were made in the congruent condition), it remains speculative whether or not an action effect was really obtained. This is because in the test phase, the tone was used as imperative stimulus with a congruent and incongruent condition. This may imply that new associations must be formed to complete the task. Thus instead of finding an action effect, their findings might suggest that people can learn stimulus response mappings better if they correspond to previously learned associations. However, Mommer (2011) claimed to have found an action effect and that the tone primed the motor chunk it was previously mapped to in the acquisition phase. This was because the moment of tone presentation in the acquisition (immediately after R1 of after R4 of the sequence) revealed similar results on sequence execution when the tone was later used as imperative stimulus in the test phase. To be more specific, the onset time of the response tone (after R1 or after R4) only affected the response time of the first response (T1) of the to-be-executed sequence, when to tone was used as an imperative stimulus in the test phase.

To further our understanding whether or not an action effect can become associated with motor chunks and to scrutinize the role such an effect might play, the present study proposes several changes to Mommer's (2011) design. First, participants only executed four 4-key sequences which were executed in both the acquisition and test phase. Out of the four sequences, two sequences started with the same first stimulus (S1) and the other with another S1. Second, the present study had the onset time of the response tone set immediately and only after the first response (R1) of the sequence in the acquisition phase. Last, to exclude the possibility to form new associations during the test phase, the present study refrained from using an auditory stimulus as imperative stimuli in the test phase.

We hypothesized that if an association would be formed between a specific motor chunk and a specific tone, changing the mapping between the corresponding sequence and tone would lead to an increased reaction time. If this is true, then it might be possible to induce a slowing that cannot be attributed to a pure stimulus-response association, with higher order event codes. Based on this assumption, we hypothesized that this slowing may be caused by three alternative reasons. Our first hypothesis was that the response tone, used as action effect in the acquisition phase, affects all the individual responses (T1, T2, T3 and T4) within the sequence when we would change the mapping between the corresponding sequence and tone. The second hypothesis was that the action effect primes the selection of a motor chunk, in this case, we only expected an increased reaction time on the first response of the sequence (T1), whilst the other responses remain unaffected (T2, T3 and T4). Last, it could be that the tone only becomes associated with the response that generated it (R1) but not with the entire motor chunk. In this case we also expected an increased in reaction time at the first response (T1) and not on the other responses (T2, T3 and T4), when we would change the mapping between the corresponding sequence and tone. Note that, although the second and third hypotheses predicted the same outcome in sequence execution, but are due to a different reason. Therefore, the present study has been designed to see if an action effect can become associated with a motor chunk and if this is indeed possible, scrutinize the role the action effect might play in sequence execution.

Method

Participants

Twenty four students (6 male and 18 female) between 18 and 32 years (mean age 21.45, SD 3.62) participated in exchange for course credits. The study had been approved by the ethics committee of the University of Twente.

Apparatus

E-Prime© 2.0 professional was used to achieve stimulus presentation, timing and data collection. Controlled by a Pentium© IV class PC whilst all unnecessary Windows XP© services were turned off to increase RT measurement accuracy. Stimuli were presented on a 15-inch Phillips 107T5 CRT monitor running at 1025 by 768 pixels resolution in 32-bit color and refreshing at 75 Hz. Responses were made on a standard QWERTY keyboard.

Task

For each participant the experiment involved executing four structured keying sequences. Responses were made with the left and right middle- and index finger, pressing the ´V´, ´C´, ´N´ and ´B´ keys respectively. The sequences were manipulated across participants so that they had two sequences starting with the same first stimulus (S1), the other two with another S1. Keys were counterbalanced across sequential positions to ensure an equal contribution on RTs at each sequential position and finger. For example, one participant had the following sequences: BVCN, BNCV, NCBV and NVCB, another had CNBV, CVBN, VCBN and VNBC. In total sixteen different sequences were used.

A trial started by presenting four horizontally aligned outlines of squares on the monitor and the sequence was initiated by filling one of the squares (lime) green. Immediately after depressing the first correct response (R1) a response tone, specific to that sequence, was presented. The square was emptied and the next square was filled (S2) until the next response (R2) was made. Then the following square (S3) was colored and so on until all four responses were made. After a full second the next trial started. The tones used in the experiment had the following frequencies: 220Hz, 440Hz, 880Hz and 1760Hz. In order to optimize discrimination between the sequences starting with the same response, the lowest frequency (220Hz) and the second highest frequency (880Hz) were linked to the sequences starting with the same S1. The second lowest frequency (440Hz) and the highest frequency (1760Hz) were used for the other two sequences. For example, this would lead to the following response scheme B(220Hz)VCN, B(880Hz)NCV, N(440Hz)CBV and N(1760Hz)VCB.

A message "ERROR try again" was displayed when the wrong response was made. It remained visible for one second before a new attempt could be made. Also if a key was prematurely pressed during a pause, participants received a warning "premature response, try again" before they were able to continue.

The experiment was divided into two parts, a practice phase and a test phase. The practice phase consisted of four practice blocks. Each block had four different sequences which were presented in random order and each sequence was repeated for 50 times with a small 40 second break halfway the block. Between each block a 3 minute break was implemented. At the end of the practice phase each sequence had been repeated for 200 times (800 trials in total).

The test phase consisted of 40 trials per sequence (160 in total). The test phase was divided into two sub-blocks, also including a 3 minute break. The order of the sub-blocks was balanced across participants and involved a congruent and incongruent condition. The congruent condition had the same tones that were previously linked to a specific sequence, whilst the incongruent condition always changed to the tone of the other sequence that started with the same S1. If we take the same example as mentioned above, the final block would change from B(220Hz)VCN, B(880Hz)NCV, N(440Hz)CBV and N(1760Hz)VCB to B(880Hz)VCN, B(220Hz)NCV, N(1760Hz)CBV and N(440Hz)VCB. Once all the trials had been completed participants saw a message indicating that they were done with the experiment.

Procedure

Upon arrival, participants signed an informed consent form and received written instructions concerning the to-be executed task. At the beginning of the experiment, an example was shown for clarification purposes and participants could ask the experimenter for extended instructions if required.

The example instructed to position the left middle- and index finger on the keys C and V respectively and the right index- and middle finger on the B and N keys respectively, using a QWERTY keyboard. In addition, the template showed the basic layout of the experiment: presented on a white background four horizontally aligned outlines of squares 9 by 11 mm in the center of the screen with the corresponding key assigned into it (key was not visible during the experiment). The squares were configured with the same spatial arrangement as the assigned/associated keys. The squares remained visible during the entire experiment. After participants felt confident to start the experiment, they put on a headphone and started with the practice phase.

Results

The acquisition phase

The practice phase was merely meant to induce chunking and to form a chunk-tone association for the four sequences. Before the reaction times analyses, trials with at least one error were removed from the data set. Outliers were identified and removed when their scores deviated more than ±1.5SD from the observed mean. A repeated measures ANOVA was conducted on reaction times with a Block (4) x Key (4) design, with Block and Key as within-subject variables. This revealed a main effect of Block $F(3,12)=47.6$, $p<.01$ and Key $F(3,15)=502.8$, $p<.01$. In addition a Block x Key interaction was found, $F(3,12)=45.1$ $p<.01$. This showed that sequence response times at T3 and T4 had an improved learning curve in comparison to the sequence response times at T1 and T2. Analysis revealed that error proportions at key 1, 2, 3 and 4 were 1%, 2.8%, 1.8% and 0.4% respectively and were not significantly different $F(3,12)=0.6$, $p>.73$ Average errors did not exceed 3.1% per key per block.

Test phase

Again outliers and trials with at least one error were removed from the data set. Outliers were identified when their scores deviated more than ±1.5SD from the observed mean. An ANOVA was conducted on reaction time with Key (4) and Congruency (2; congruent vs.

incongruent), as within-subject variables. This showed a significant main effect for Key F(3,75)=592.2, p<.01, but no significant main effect was found for Congruency F(1,25)=0.04, p>.83. And no Key x Congruency interaction was found F(1,75)=0.44, p>.75. These findings imply that no congruency effect occurred between the two conditions as can be seen in Figure 1.

An analysis on arcsine transformed error proportions revealed no significant difference between the conditions F(1,75)=0.49, p>.73. Average PE's did not exceed the 2.4% errors per key in both conditions. The observed error proportions were 1.8%, 2.4%, 2.1% and 1.6% in the congruent condition at R1, R2, R3 and R4 respectively and 1.9%, 2.4%, 2.2% and 1.7% in the incongruent condition at R1, R2, R3 and R4 respectively.

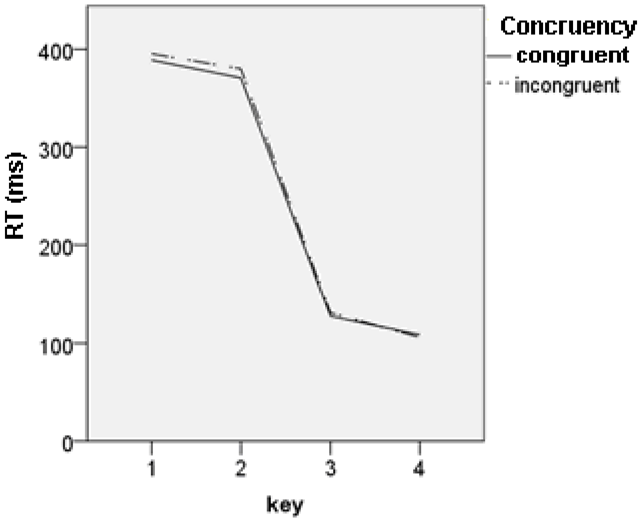

Figure 1. The mean reaction times of the different responses within each sequence in the test phase. The congruent condition had the same key-to-tone-mapping as was practiced in the acquisition phase. The incongruent condition had changed the key-to-tone-mapping with the sequence that started with the same S1.

Discussion

The purpose of the first experiment was to explore the possibility that a stimulus may be associated as action effect with an entire motor chunk (Verwey, 1996, 2001). An action effect can best be seen as a bidirectional association that the agent forms between movement of their body (action) and the co-occurrence of the perceivable outcome (effect). According to TEC this is possible because any kind of sensory event that repeatedly follows action may induce an action effect (Hommel et al. 2001). The data however, did not support this premise because no significant difference was found between the congruent and incongruent conditions. In retrospect these findings are not surprising and may be the result of a design flaw, and/or the complexity of the task. Recall that each participant had executed four sequences, of which two started with the same S1 and the other two with another S1. Therefore, the only way to distinguish the difference between the sequences that started with the same S1 was the tone that was linked to that specific sequence, presented at the same time with the second stimulus (S2). This uncertainty reflected on the relatively slow response times at T2 (see figure 1). Therefore, it seems that participants formed a single response (R1) and one motor chunk (R2-R3-R4) per sequence, instead of one motor chunk. Furthermore, no significant interaction effect had been found between the keys and congruency. This suggests that the tone did not become associated with a specific key (R1), but might have been used in combination with S2 to select and/or execute the second motor chunk (R2-R3-R4). However, if the tone became associated with the motor chunk, we would have expected faster responses in the congruent condition at T2 as compared to the incongruent condition, which we did not observe. In sum, the results of Experiment 1 did not allow us to answer our hypotheses properly and therefore a second experiment was conducted.

Experiment II

The second experiment extends the first study to investigate if an action effect can be associated with a motor chunk (Verwey, 1996, 2001). Participants still executed four different sequences, of which two started with the same initializing stimulus (S1) the other with a different S1. The results of the first experiment suggested that it had been too complicated for participants to properly distinguish the sequences that started with the same stimulus (S1), at least, until the second stimulus (S2) was presented. Therefore, instead of practicing four different sequences per block only two sequences were executed per block. In addition, the sequences that started with the same stimulus (S1) were presented in different blocks. Thus, in each block participants performed two different sequences that both started with a different S1.

As with Experiment 1, a specific response tone was linked to each sequence (presented immediately after R1). We did not have an exact idea of what might happen, because people still executed different sequences with the same starting stimulus (S1). But because this conflict was split between blocks, we expected that people no longer created a single response and a motor chunk per sequence, as was observed in Experiment 1. If indeed just one motor chunk would be formed per sequence, we still expected that an association would be formed between a specific motor chunk and a tone presented after R1, because by then that motor chunk has been selected. Furthermore, in the test phase the auditory stimulus was presented simultaneously with the visual stimulus S1 in a congruent and incongruent condition. This was done to investigate whether the tone would prime the sequence or a specific response (R1). Our hypotheses remained the same as with Experiment 1, namely, that if the tone indeed becomes associated with the entire motor chunk, faster responses would be made in the congruent condition as compared to the incongruent condition. If this is true, then we proposed three alternative explanations for why this might occur. First, the response tone, used as action effect in the acquisition phase, affects all the individual responses (T1, T2, T3 and T4) within the sequence when we change the mapping between the corresponding sequence and tone. Second, the response tone, used as action effect in the acquisition phase primes the selection of a motor chunk, in this case, we only expected an increased reaction time on the first response of the sequence (T1), whilst the other responses remain unaffected (T2, T3 and T4). Third, it could be that the tone only becomes associated with the response that generated it (R1) but not with the entire motor chunk. In this case we also expected an increased in reaction time at the first response (T1) but not on the other responses (T2, T3 and T4), when we would change the mapping between the corresponding sequence and tone.

Method

Participants

16 students (8 male and 8 female) between 19 and 30 years (mean age 23.44, SD 3.5) participated in exchange for course credits. The study had been approved by the ethics committee of the University of Twente.

Task

The same sequences were used as with Experiment 1, and participants practiced four different sequences. Again, the sequences were configured so that out of the four sequences, two of each started with the same stimulus. Thus, out of the four sequences, two started with the same S1 and the other two sequences started with another S1.

The acquisition phase consisted of four practice blocks. A similar draft was used as in Experiment 1 and again, immediately after the first correct response (R1) a tone specific to that sequence was presented. This time however, only two sequences were presented per block which started with a different S1. The sequences were each repeated a 100 times in each block and participants had a 40 seconds break halfway through the block. Once all the trials in a block had been completed, a 3 minute break was implemented and the next block started. The second block involved two different sequences but had the same initializing stimulus (S1) as the sequences that were executed before. The third block was identical to the first practice block and the fourth was the same as the second practice block. At the end of the practice phase all sequences were repeated along with the tones for 200 times.

The test phase involved two test blocks. Each test block had the same two sequences that were presented in the different blocks of the practice phase. Thus, one test block had the same sequences as the practice blocks one and three. The other test block had the same sequences as was practiced in blocks two and four. The order of the test blocks was balanced across participants. This meant that half of the participants were first tested with the sequences that were practiced last (practice block 4) and the other half with the sequences of the last but one practice block (practice block 3).

In the test phase, the tone (presented immediately after R1 in the acquisition phase) was presented at the exact same time as the S1 of the to-be-executed sequence. However, the tone either randomly matched (congruent), or mismatched (incongruent) with the sequence that it was previously linked to in the practice phase. This was done to avoid task biasing and meant that the participants could not use different strategies to perform the task between the congruent and incongruent condition. Rather, this implies an automatic process because participants could not predict whether the tone would be congruently or incongruently mapped to the sequence. Again, in the congruent condition the tone was presented with the same sequence as was practiced in the acquisition phase, the incongruent condition had the tone always switched to the sequence that had the same starting stimulus (S1). Each condition consisted of 20 trials per sequence (40 trials per sequence, 160 in total). Once all the trials were completed, participants were asked to fill out a questionnaire testing their explicit knowledge about the executed sequences.

Procedure

The same procedure was maintained as with Experiment 1, only an additional explicit knowledge questionnaire at the end of the experiment was administered. The questionnaire consisted of three parts. First, participants were asked to write down which sequences they had executed in free recall format. In addition, they were asked to indicate how confident they were about their answers. The confident scores were later used to predict awareness of the explicit knowledge about the sequences. The second part showed the sixteen different sequences used in this study and participants were asked to recognize the four sequences they had executed. Again they were asked to indicate how confident they were about their answers. The last part asked participants to indicate which strategy they had used to answer the first two questions in multiple choice format. Furthermore, participants were asked to indicate whether they played videogames, piano, any other instrument or sports on a 3 point Likert scale. All answers entailed the average hours spent practicing in a week, for how long they have been practicing and if they still practiced that particular hobby.

Results

The acquisition phase

The practice phase was meant again to induce chunking and to form a chunk-tone association for the four sequences. Before the reaction times analyses, outliers and trials with at least one error were removed from the data set. Outliers were identified when their scores deviated more than ±1.5SD from the observed mean. A repeated measures ANOVA was conducted on reaction times with a Block (4) x Key (4) design, with Block and Key as within-subject variables. This revealed a main effect of Block $F(3,12)=305.1$, $p<.01$ and Key $F(3,15)=139$, $p<.01$. The results showed that participants' response times reduced with practice. In addition a Block and Key interaction was found, $F(3,12)=27.1$, $p<.01$. The interaction effect between Block and Key showed that response times at T1 were relatively slow as compared to the other responses, which was expected because up until stimulus presentation there remained uncertainty to which sequence would be presented. A closer inspection revealed that the second block had similar response times as the first block F(1,3)=4.28, p=0.5. The other successive blocks were executed faster in terms of reaction times between blocks 1 and 3 F(1,3)=34.6, p<.01, and between blocks 2 and 4 F(1,3)=35.8, p<.01. No significant difference was found between blocks 3 and 4 F(1,3)=2.0, p=0.7. The average response times for sequence execution were 202.5 ms, 207.0 ms, 168.3 ms and 167.8 ms for block 1, 2, 3 and 4 respectively. Analysis on arcsine transformed error proportions did not reveal significant differences (p=0.3). Errors made at R1, R2, R3 and R4 were 0.7%, 2.3%, 2.0% and 0.8% respectively.

Test phase

Again trials with at least one error and outliers were removed from the data set. Outliers were identified and removed when their scores deviated more than ±1.5SD from the observed mean. An ANOVA was conducted on reaction times with Key (4) and Congruency (2; congruent vs incongruent), as within-subject variables. This showed a significant main effect for Key F(3,45)=376.9, p<.01, but no significant main effect for Congruency F(1,15)=2.84, p=0.11 and a marginally significant congruency effect between Key x Congruency F(3,45)=2.56, p=.067. The latter results suggested that the tone might have a weak association with the response that generated it.

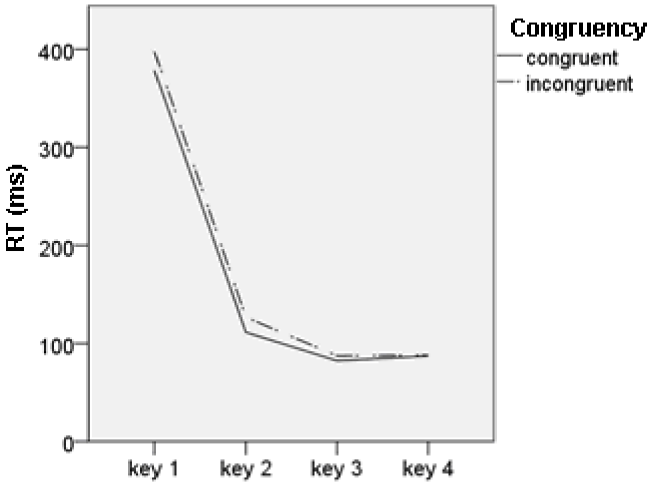

Figure 2. The mean reaction times of the different responses within each sequence in the test phase. The congruent condition had the same key-to-tone-mapping as was practiced in the acquisition phase. The incongruent condition had changed the key-to-tone-mapping between the sequences that started with the same S1.

To further inspect if the tone became associated with the entire motor chunk or a single response, we looked at the total duration of the executed-sequences between the congruent and incongruent condition. Therefore, all the individual responses within each sequence were combined, averaged and grouped according to the to-be-executed sequence. This led to four different sequences per participant, a paired t-test was conducted and revealed a significant difference between in favor of the congruent condition T(3)=7.1, p<.003, (see Figure 3).

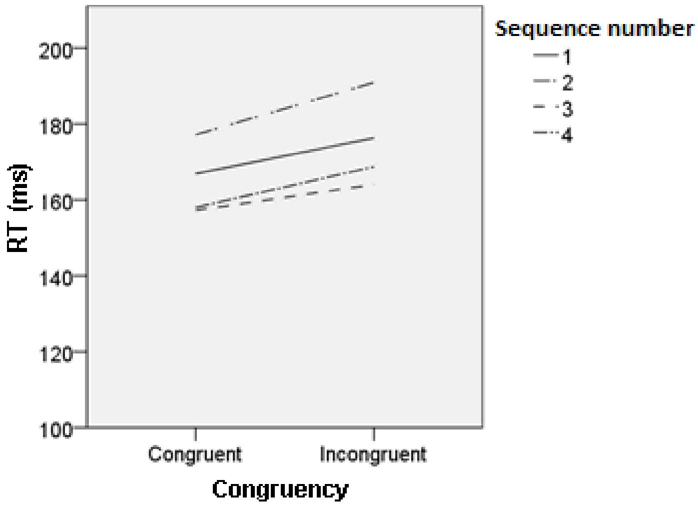

Figure 3. The mean reaction times of the different sequences in the test phase. The congruent condition had the same key-to-tone-mapping as was practiced in the acquisition phase. The incongruent condition had changed the key-to-tone-mapping between the sequences that started with the same S1.

Lastly, an analysis on arcsine transformed error proportions revealed no significant difference between the conditions and keys F(3,45)=0.86 p=0.96 Average errors made per key in the congruent condition were as followed: 1%, 2.5%, 2.6% and 0.6% for keys 1, 2, 3 and 4 respectively, for the incongruent condition 1%, 2.5%, 2.7% and 0.5% for the keys 1, 2, 3 and 4 respectively.

The explicit knowledge survey held at the end of the experiment revealed that people had limited awareness of the extensively rehearsed keying sequences. Out of the sixteen participants, six (37.5%) recalled all four sequences at the free recall question correctly. This reduced to 25% when participants were asked to recognize the executed sequences. Only three participants (18.75%) recalled two or less sequences at the free recall question. Four participants (25%) recognized only two or less sequences correctly at the recognition questionnaire. However, participants were quite good in assessing whether or not they recalled the executed sequences correctly (r=.86, p<.05). In addition, explicit knowledge of the executed sequences did reflect on the mean reaction times (r=-.56, p<.05). This finding would suggest that higher awareness leads to somewhat faster response times. Interestingly, a closer inspection revealed that recognizing the executed sequences predicts response times for the congruent condition (r=-.53, p=.03) and incongruent condition (r=-.60, p=.02) whereas the free recall questionnaire did not (p>.05). Finally, the replies made on how participants had tried to write down the executed sequences showed that, out of the sixteen participants, seven (44%) indicated that they remembered the spatial locations of the stimuli and/or keys, six (37.5%) indicated that they tried to replay the sequence in their mind or by tapping on the table. The remaining participants indicated to have used a combination of both strategies.

Discussion

The data from Experiment 2 showed that the individual responses within each sequence behaved very similar between the different congruency conditions. We hypothesized that if the tone indeed becomes associated with the entire motor chunk, faster overall responses would be made in the congruent condition as compared to the incongruent condition. On the other hand, if the tone influences the selection of a motor chunk *or* if the tone only becomes associated with the response that generated it (R1), we expected only T1 to be affected whilst the other responses (T2, T3 and T4) remain unaffected.

The data showed relatively slow responses at the first key press (T1), whilst the other responses (T2, T3 and T4) remained nearly unaffected, at least when we looked at the interaction between congruency and the keys. The level of significance observed for the congruency effect was marginally at best. This may still suggest that the tone, used as an action effect in the acquisition phase, only became associated with the response that generated it (R1), although this association would be very weak at best.

The paired t-test however, revealed a strong effect in favor of the congruent condition. This implies that the tone modulated response execution at least one way or another. The problem with the paired t-test is however, that it does not allow for discrimination within the individual responses. Therefore we can neither rule out whether the tone becomes associated with the response that generated it (R1), nor can we rule out the possibility that the tone reflects a motor chunk selection process.

General discussion

The purpose of the present paper was to explore whether an action effect can be associated with motor chunks (e.g., Verwey, 1996, 2001). Basically, an action effect can best be seen as a bidirectional association that the agent forms between the movement of their body (action) and the co-occurrence of the perceivable outcome (effect). Because these associations work in either direction, from motor code to sensory code and vice versa, they allow people to recruit movement by activating a sensory effect. According to our theoretical framework TEC this is possible because any kind of sensory event that repeatedly follows action may induce an action effect (Hommel et al. 2001). The notion behind TEC is that cognitive representations of events are represented in terms of event codes that represent the distal features of an event, such as size, distance, color, movement, spatial orientation or auditory cues. Together, they may become integrated into a higher order event code and represent goals or intentions set by the agent.

We hypothesized that, if an association would be formed between a specific motor chunk and a specific tone, changing the mapping between the corresponding sequence and tone would lead to an increased reaction time on all the responses (T1, T2, T3 and T4). On the other hand, it was also plausible that the tone would just become associated with the key that generates it (R1). In that case, we expected only T1 to increase when we would change the mapping between corresponding sequence and tone, but not the other responses (T2, T3 and T4). Our last hypothesis was that the tone would reflect a selection process. If this would be the case, we also expected an increased reaction time on the first response (T1), but not on the other responses (T2, T3 and T4).

To investigate this matter, we had participants perform four 4-key sequences with a specific response tone linked to each specific sequence (presented after R1). After some practice, we either kept the tone similar to the same sequence as was rehearsed before (congruent condition), or changed the response tone to that of a different sequence that started with the same stimulus (S1) (incongruent condition).

The results of Experiment 1 showed that people formed a single response (R1) and a motor chunk (R2-R3-R4) per sequence instead of one. Furthermore, the data showed no support for our hypotheses because we did not find any significant differences between the congruency conditions, nor did we find any interaction between the keys and congruency. The latter suggests that the tone did not become associated with the response that generated it (R1). Also, if the tone reflected a selection process we would have expected to find a congruency effect at T2, which we did not find.

The second experiment extended the prior study to further our understanding whether an action effect can be associated with motor chunks. Experiment 2 had participants perform only two different sequences per block instead of four. The two sequences that were presented in each block, both started with a different initializing stimulus (S1) but the same initializing stimuli (S1) were used in two different sequences in the following block. The results showed that each sequence was represented as a single motor chunk (Verwey 1996). In addition, the findings of Experiment 2 showed a promising step in finding an association between a higher order event code and a motor chunk. Namely, we found a significant difference, in terms of execution times, in favor of the congruent condition as compared to the incongruent condition. That is in line with our main hypothesis that if an association would be formed between a specific motor chunk and a specific tone, changing the mapping between the corresponding sequence and tone would lead to an increased reaction time on response execution. However, the difference between congruency was only demonstrated with the paired samples t-test and not with the ANOVA's. Although this is surprising, the problem is that the paired t-test does not allow for discrimination between the individual responses within each sequence. Therefore, we cannot infer to what might have caused this difference and consequently we cannot make a distinction between our hypotheses. Rather, we can only conclude from the data that the tone provides a non-robust congruency effect in the expected direction.

In line with our findings, Kunde, Elsner and Hoffmann (2004), found that once a response effect deviated from an expected effect, motor responses suffered in terms of response times and accuracy. Although, we advise caution to analogously compare these findings, Kunde et al. (2004) study involved rhythm rather than speed. Both studies however, derived from the notion that action is represented in terms of cognitive representations of their anticipated effects (e.g., Hommel et al. 2001). The present findings are in line with TEC's assertion that cognitive representations of events are represented in terms of event codes that represent the distal features (sound effect) of an event, rather than proximal features (motor responses). Indeed in the realm of the DSP-task (e.g., Verwey, 1999), it has been shown that participants have little awareness of even highly practiced keying sequences (Verwey et al. 2009; 2010). The explicit knowledge questionnaire administered at the end of experiment 2 showed a similar finding.

In conclusion, the present study showed a non-robust congruency effect in the expected direction. In addition, our findings are in line with TEC (Hommel et al. 2001) because the presented results showed that cognitive control relates more to the (anticipated) effect it has on the external world, rather than the inner mechanics that underlie these actions. However, because we could not discern between the hypotheses as to why this effect occurred, future research is clearly needed. We encourage future research to extend our design by looking at how action effects behave between multiple layers of congruency within each sequence. In other words, we only tested how a tone used as an action effect presented after R1 of a sequence, would influence responses when we later used that same action effect with another sequence that started with the same stimulus (S1; and thus the same R1). To fully scrutinize the role of an action effect with movement sequences, it would be essential to investigate whether or not such an action effect would influence responses of an entire different movement pattern. Or perhaps more interestingly, what would happen if we would change the first stimulus (S1) but keep the remaining stimuli (S2, S3 and S4) the same? We believe that more research on this topic would provide a more elaborate understanding of the exact role an action effect plays within movement sequences.

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