The Role of Attention in Predictive and Postdictive Sense of Agency

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Abstract

Sense of agency is the awareness of controlling one’s own intentional actions and through them generating events. Previous theories argued that sense of agency is constructed with either a predictive mechanism before the action or a postdictive mechanism after the outcome occurred. A third view suggested that both mechanisms contribute to the sense of agency depending on the predictive and postdictive cues’ availability and reliability. On other hand, previous studies showed that since this sense is on the awareness, current cognitive load and attention level may affect how much agency is felt. However, in those studies dominantly predictive mechanisms of the sense of agency were active. Therefore, if such an effect occurs for the postdictive sense of agency, too remains unclear. In the present study, the effect of the cognitive load on predictively and postdictively constructed sense of agency is examined separately by using intentional binding paradigm. The intentional binding of the participants is compared when they have high and low cognitive loads that stem from a working memory dual task.

*Keywords*: sense of agency, predictive, postdictive, attention, cognitive load, working memory

The Role of Attention in Predictive and Postdictive Sense of Agency

Sense of agency refers to the subjective feeling of controlling one’s own actions and through them generating events in the environment (Haggard & Tsakiris, 2009). Wittgenstein (1958) raised a question that has become famous, “What is left over if I subtract the fact that my arm goes up from the fact that I raised my arm?”. The difference between raising someone’s own arm intentionally and the arm going up by itself may be the sense of agency. There is a growing debate on how the sense of agency is constructed, whether the predictive mechanisms are used to construct it prospectively or if it is generated only after the outcome occurrence with inferential processes. Different factors may be at work in these two mechanisms. Recently, it was found that the level of attention affects how much agency individuals feel (Wen, Yamashita, & Asama, 2015). Yet, in those studies, predictive and postdictive processes of the sense of agency are not dissociated and the focus is on the predictive mechanisms. Whether the level of attention has a similar effect on the postdictive sense of agency remains open to question. This project tries to answer this by using the Intentional Binding Paradigm (Haggard, Aschersleben, Gehrke, & Prinz, 2002).

*Predictive vs. Postdictive Sense of Agency*

One influential theory on the sense of agency is the ‘Comparator Model’ developed by Blakemore and Frith (Blakemore & Frith, 2003). According to this model, there are representations of the motor commands and their outcomes in the motor system. While the motor command is being generated, a component in the motor system predicts the outcome of the motor command by using its representation. This prediction is done through internal forward models that are built via sensory feedback based on copies of the actions which are called the efference copies. The predicted outcome is compared with the actual outcome. If the two matches, the sense of agency is constructed. Although the sense of agency is constructed only after the actual outcome, agents are informed by their motor commands before the action and predict the outcome.

Another theory suggests that the sense of agency is only built retrospectively after the outcome (Wegner & Wheatley, 1999). According to this view, contrary to what Comparator Model claimed, individuals are not informed by their actions and actions’ consequences. But rather some unconscious factors lead the actions and also some unconscious factors create the thought of the action. The outcomes connect with the thought retrospectively and are perceived as if the intention generated the action. This mechanism works in this way if three main principles are met. If the thought occurs before the action (priority), the action and the thought are consistent (consistency) and no other alternative explanation is available (exclusivity), the action is attributed to the self.

*Combining Both Mechanisms*

A third view in the debate argues that these two mechanisms do not have to be mutually exclusive but both prospective and retrospective mechanisms can contribute to the construction of the sense of agency. (Moore & Haggard, 2008; Synofzik, Vosgerau, & Newen, 2008). In their study, Moore and Haggard (2008) isolate the predictive and postdictive parts of the sense of agency and show the existence of both. They compare how much agency participants feel in two actions that have different probabilities to produce an outcome.

In one condition, pressing a button produces a voice outcome 75% of the time whereas in the other condition the probability is 0.5. Results shows more implicitly measured sense of agency in 0.75 probability condition than the ones which are in 0.5 condition even in the trials that there is, in fact, no outcome. Since there is no outcome, the agency could not be constructed after the outcome and the difference in the level of sense of agency must be caused due to relying on the predictive mechanisms.

Similarly, Moore and Haggard (2008) also compare the level of agency felt over the actions having the same 0.5 probability to produce an outcome when the action do produce an outcome and when it does not. In the trials in which the action produces an outcome the level of implicitly measured sense of agency is higher than the ones in which there is no-outcome. Since the predictive cues are the same for the two conditions, what makes the sense of agency differ is the existence of the outcome. Thus, the postdictive mechanism is active in the construction of the sense of agency.

  In the same line with the study of Moore and Haggard (2008), Optimal Cue Integration Theory was developed (Synofzik, Vosgerau, & Lindner, 2009). According to this theory, there are various cues regarding the sense of agency that are integrated by the brain. These cues have different weights depending on their availability and also reliability (Synofzik et al., 2009). In that framework, cues that are generated by the predictive component of the motor system are the most salient and reliable ones (Wolpert & Flanagan, 2001). Yet, if predictive cues are weak as in the study of Moore and Haggard (2008), then postdictive cues can gain importance to infer agency. On the other hand, when the predictive cues are strong enough, prediction of the outcome is sufficient to create the sense of agency without the need for outcome’s actual occurrence (Moore & Haggard, 2008). Therefore, both predictive and postdictive mechanisms contribute to the sense of agency and the level of these underlying processes’ activation show differences depending on the conditions.

*Attention*

Although many studies have been targeting to explain the mechanism of sense of agency construction, little has been known about features of the processes such as attention-dependency. Whether sense of agency depends on attentional and cognitive resources or it is an automatic process has become a question recently. One study investigating the role of cognitive resources in the sense of agency, compared how strong sense of agency is felt in two different levels of cognitive load situations with the assumption that if the sense of agency is reliant on cognitive resources, it is affected by the available cognitive load capacity (Hon, Poh, & Soon, 2013). In the study, participants were asked to perform a simple motor action which is moving a dot on the screen with the mouse while keeping either 2-digit or 7-digit random letters in the mind. The results revealed that high cognitive load lead less sense of agency report than low cognitive load. They summarize their findings as preoccupied mind feel less sense of agency. Another study using the same experimental method showed that arousal that is generated by the perceptual feature of the stimulus lead to stronger sense of agency. One other study investigating attention role on reconstruction of conscious intention showed that when participants were told to report the temporal information of a single event in intentional action processes such as intention, action or the outcome moment, the level of sense of agency they felt was lower than the condition that the participants focused on every step of intentional action since focusing the attention on a single event prevent them from allocating their attention to the reconstructive process of agency (Haggard & Cole, 2007).

*The Present Study*

Although these studies shed light on the attention and the sense of agency relation, in none of the studies predictive and postdictive processes were differentiated. Instead, in the actions in all of the studies, predictive cues were highly reliable and salient since 100 % of the time the action produced an outcome. Therefore, the agency construction process in the aforementioned studies relies on mostly predictive mechanisms. Although attention seems like having an effect on the process of sense of agency construction, it is not clear which part of the process it influences. Whether it has a role in only the creation of the predictive representations or postdictive processes which relies on the comparison of the action and outcome are also dependent on the attentional resources are open to question.

One study tried to examine the attention role in both postdictive and predictive processes (Wen, Yamashita, & Asama, 2016) Yet, in that study, the way of authors constructing the postdictive mechanism was giving the participant a specific goal to track. They aimed to lead participants to use postdictive cues by giving them a specific location on the screen to move the dot inside. However, in that way together with postdictive cues, predictive cues were also still highly reliable and salient. Also, what was examined in this study as the postdictive mechanism was a goal-based, conceptual, judgment of agency which is different than motor-level, non-conceptual feeling of agency that is the main target of other studies examining the attention role on (Synofzik et al., 2008). So, the role of attention in the specifically postdictive integration of motor-level, non-conceptual agency remains unclear.

In the present study during the sense of agency construction attention’s role in predictive and postdictive processes are separately examined.

The dual-task is used to manipulate the attention level of participants like the previous studies did (Wen et al., 2016; Hon et al., 2013). Participants are asked to keep in their minds either 2-digit or 7-digit random letters while they perform a keypress action.

To examine the predictive and postdictive processes separately, a similar experimental set-up that was used by More and Haggard (2008) are employed. To isolate the attention role’s in predictive processes, two cognitive-load levels are compared in trials that the action does not produce any outcome in a high probability of outcome-production condition.

To examine the role of attention in the postdictive process alone, two cognitive-load levels are compared in the trials that the actions producing an outcome in low probability conditions.

It is expected to find that if the predictive cues separately are attention-dependent, in trials targeting specifically predictive sense of agency construction participants feel weaker sense of agency in high cognitive load condition than low cognitive load condition. If predictive processes of the sense of agency is not susceptible to attentional resources by itself, the level of cognitive load would not create any meaningful difference. With the same logic, if the postdictive processes require attentional resources using more cognitive resources in high-cognitive load condition lead participants to feel weaker sense of agency in comparison to participants’ having a low cognitive load in trials targeting postdictive construction of sense of agency.

**Method**

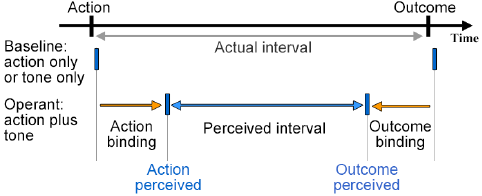
**Participants**

Based on previous studies 20 right-handed individuals with normal or corrected visual acuity will participate in the study (Moore & Haggard, 2008). They will be tested individually in a testing room.

**Measurement**

*To Measure Sense of Agency*

The intentional binding paradigm is employed (Haggard, Clark, & Kalogeras, 2002). The paradigm is based on making an inference from the perceived time of individuals’ perceiving their voluntary actions and their effects. In the studies that the paradigm is developed there are four events: (1) participants make a voluntary action of pressing a key and the keypress produces a tone, (2) participants’ finger muscle is triggered to press the key by TMS stimulation to the motor cortex and the involuntary keypress produces a tone, (3) participants press the key and the key does not produce any outcome (baseline action), and (4) participants hear the tone that is externally generated (baseline tone) (Haggard et al. 2002; Haggard, Aschersleben, Gehrke, & Prinz, 2002). In the meantime, there is a Libet clock rotating on the screen. In each of the events, participants are asked to report the time of the action and the tone, if applicable. Only in the voluntary action condition participants perceive the time of the action as shifted forward and the time of the outcome as shifted backward (See *Figure 1*). Thus, there is temporal binding between the action and the outcome in volition but not in passive action or the observation of the action. The temporal binding between the action and its effect is evaluated as the indicator of volution.



*Figure 1.* Intentional Binding. Adapted From ‘The Experience of Agency in Human-Computer Interactions: A review’ by H. Limerick, D. Coyle and J. W. Moore, 2014, *Frontiers in Human Neuroscience, 8,* p.2.

The magnitude of the binding is thought as referring to the what extent the individual feel sense of agency in a way the more temporal binding means stronger sense of agency. This result is replicated many times since it was first stated and widely accepted as a paradigm (Dewey & Knoblich, 2014; Engbert, Wohlschläger, & Haggard, 2008; Haggard & Cole, 2007; Wen et al., 2015).

In the present study, only the set-up in the voluntary action condition and baseline conditions are used to measure to what extent the participants feel sense of agency.

**Procedure**

***Experiment Blocks***

The experiment consists of fourteen blocks for each prediction-cue and postdictive-cue conditions. Each participant completes fourteen blocks of either predictive-cue or postdictive-cue tasks. Each block comprised of 32 trials. In all trials except baseline trials participants perform a keypress while keeping 2-digit or 7-digit letters.

For prediction-cue conditions, 75% of the time (24 trials in a block of 32 trials) of pressing a key produces a tone. It is assumed that sense of agency is constructed predictively in trials in which the action does not produce a tone (8 trials). Since there is no outcome in those trials, postdictive construction that happens after the outcome occurrence is not possible.

For postdictive-cue condition, the probability of the keypress producing the tone is 25% (8 trials in a block of 32 trials). It is assumed that sense of agency is constructed prospectively in trials in which the action produces an outcome. Since the probability of outcome occurrence is low to predict it, sense of agency construction is attributed to the outcome occurence.

Although the probability of outcome-production for postdictive-cue condition was 50% in the study of Moore and Haggard (2008), it is decreased with the aim of eliminating any interference from predictive process. Since the aim of the original study was to show the effect of the outcome occurrence, there was no need to eliminate predictive processes fully. Yet, in the present study to prevent predictive processes as much as possible carries an importance. If the predictive processes are active while the postdictive processes are targeted, any observed difference between the conditions with different cognitive load levels may still be stemming from the effect on the predictive processes. Therefore, it is important to decrease the predictive processes being active to the minimum level. On the other hand, decreasing it to a level that the participants do not expect tone to occur would lead a surprise effect when the outcome occurred. This would cause another confound in attentional level (Horstmann, 2015). In addition to these reasons, to make the trials that are compared in predictive and postdictive conditions equal, the probability of outcome occurrence is decided as 25% to isolate postdictive processes.

For each cue type, there are eight blocks for action-judgment. In those trials, participants are asked to judge the time of their keypress actions regardless of the outcome occurrences. In four of the action-judgment condition participants conduct low cognitive load task and in the rest of four they conduct high-cognitive load tasks. In low cognitive load condition, participants keep 2-digit random letters in their mind while they press a key. In high-cognitive load conditions, this is 7-digit random letters.

In addition to action-judgment trials, there are four blocks for tone-judgment in each cue-type blocks. Although only the action judgment is the target of the present study, to prevent participants from ignoring the tone completely time of tones is also asked (Moore & Haggard, 2008). In tone judgment trials, participants are asked to judge the time of the tone they heard. If there is no tone, participants entered a value that is instructed to represent missing values. Low and high cognitive loads are equally distributed to the tone-judgment trials, too which means two of them are in a high cognitive load and two of them are in low cognitive load conditions.

There is one baseline block for action and one for tone judgments for each cue-conditions. In the baseline conditions, participants are asked to judge the time of a keypress action that does not produce an outcome. In tone-baseline condition, participants do not take any action but judge a tone that they hear. All blocks including baselines are randomized.

In each trial of the experiment participants first are shown a black cross at the center of a screen with a gray background for 500 msec. Then, depending on the cognitive load condition either 2-digit or 7-digit strings are presented for 3 seconds.

*Procedure*

At the beginning of the block, participants are instructed to hold the string that is shown on the screen in their mind until it is asked to be reported and also to press a key with their right index finger after the clock appears anytime they choose. After the strings are disappeared, the clock with 5 min intervals appears on the screen as it was in the study of Haggard et al., (2002). The initial point of the clock-hand is randomly arranged. The clock-hand remains at the position it appears for 500 msec and then starts to rotate with a period of 2560 msec. It is specifically told not pre-determine the keypress time according to clock position like specifying a time point to press. Depending on the trial the keypress is followed with vocal outcome 250 msec after the keypress. After the participants press the key, the clock continues to rotate for a random time and then stops. Depending on the condition participants are asked to judge either the time they pressed the key or the tone they heard. Participants enter the asked-time with their left hand by using the keyboard of the computer. At the end letters are asked so that participants do not ignore the keeping the letters.

Action/Tone Jugment Baseline Action Baseline Tone

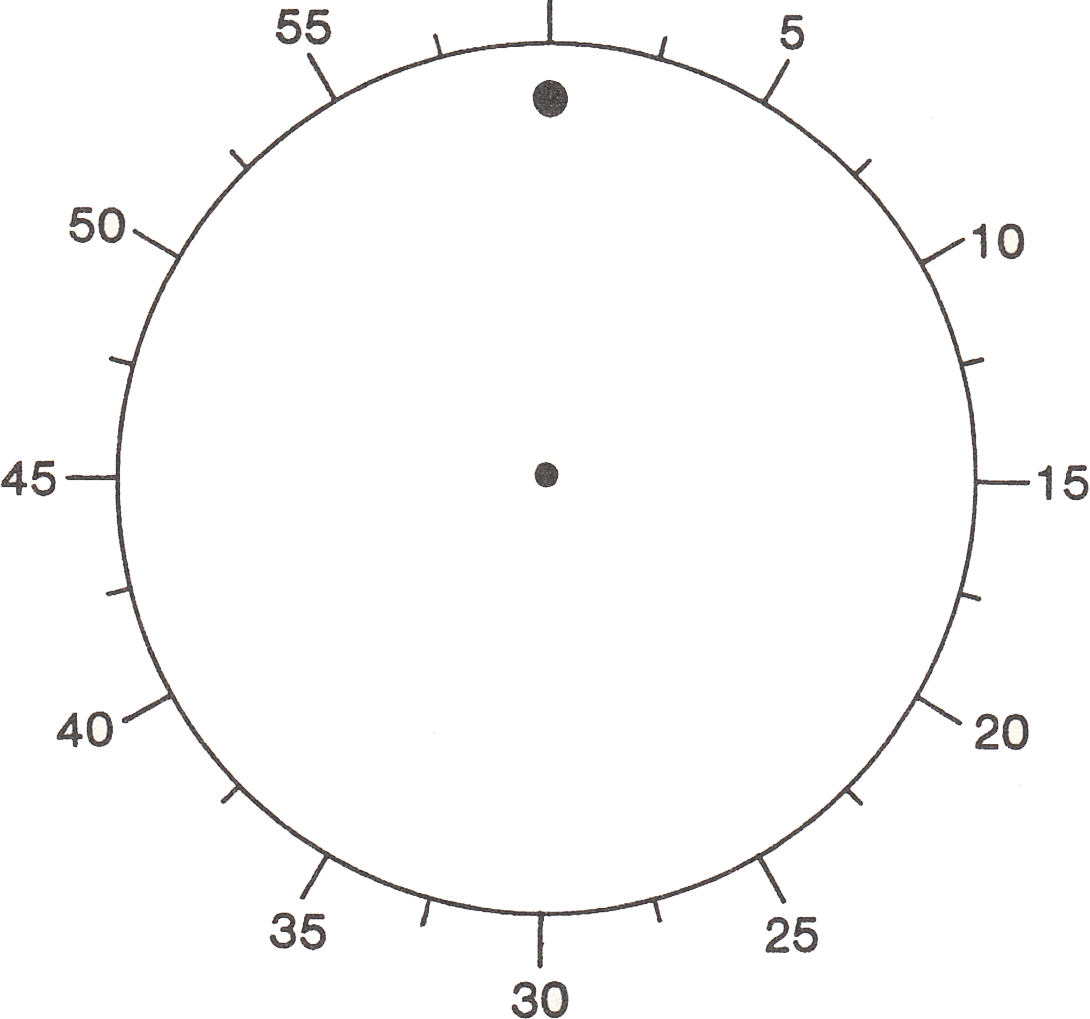
+

500ms

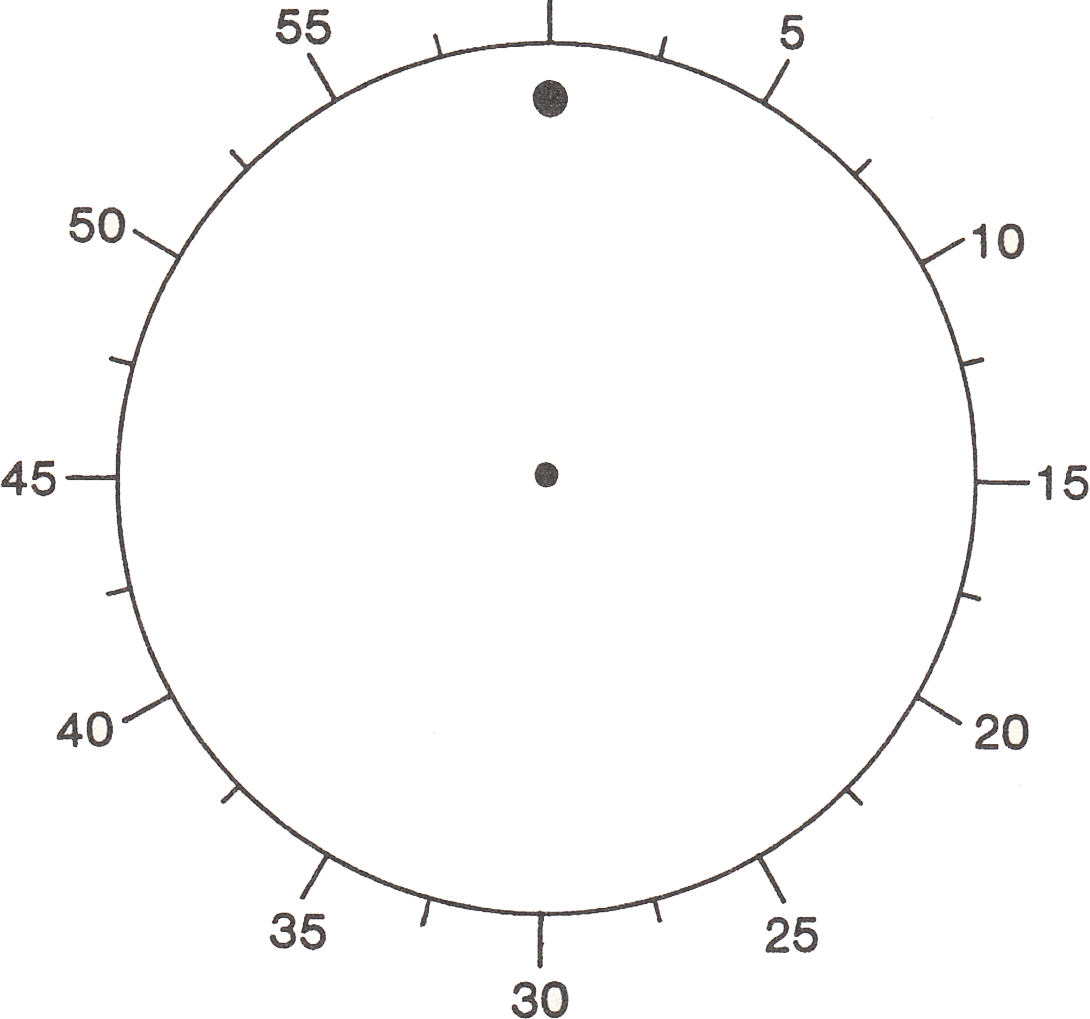
Remember the following letters

AMGLDMC or KD

3 s



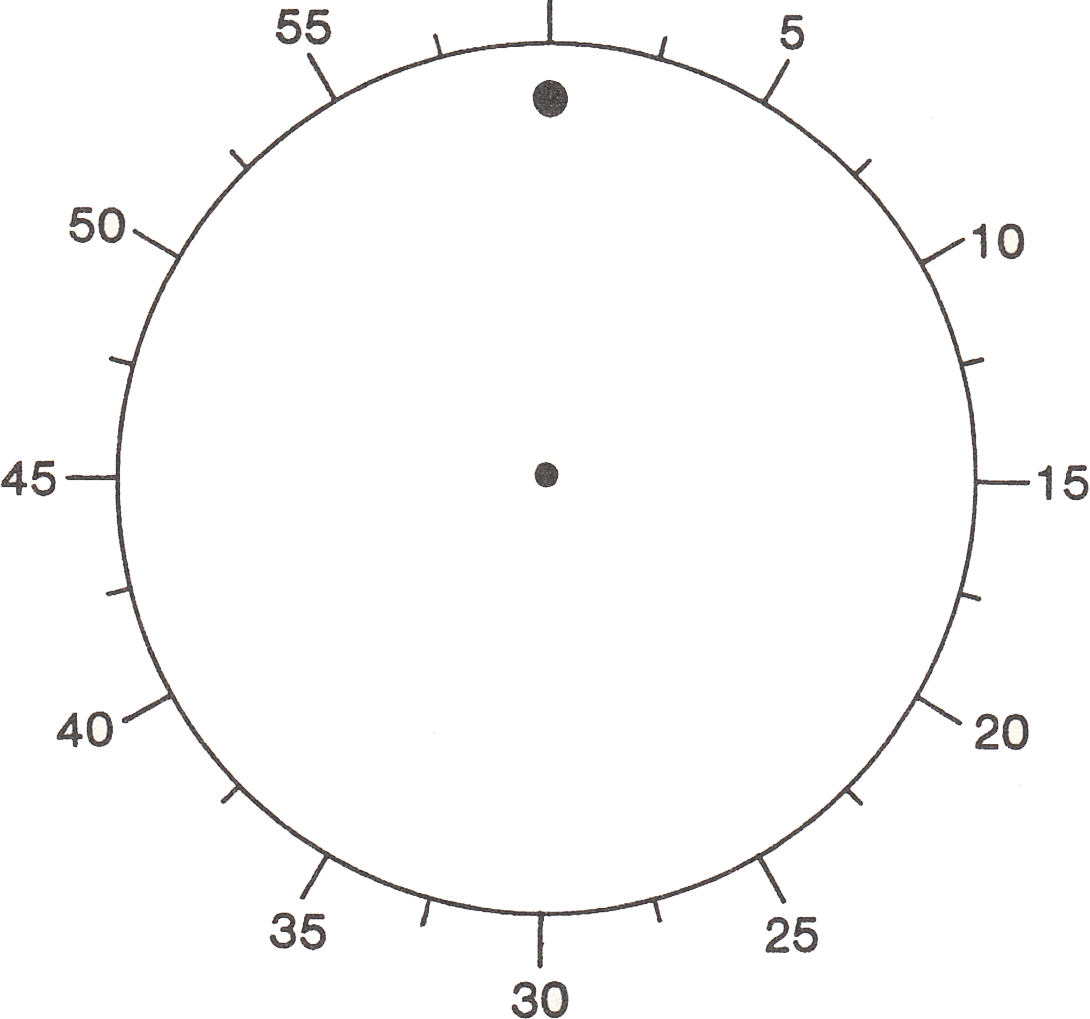
Clock appears

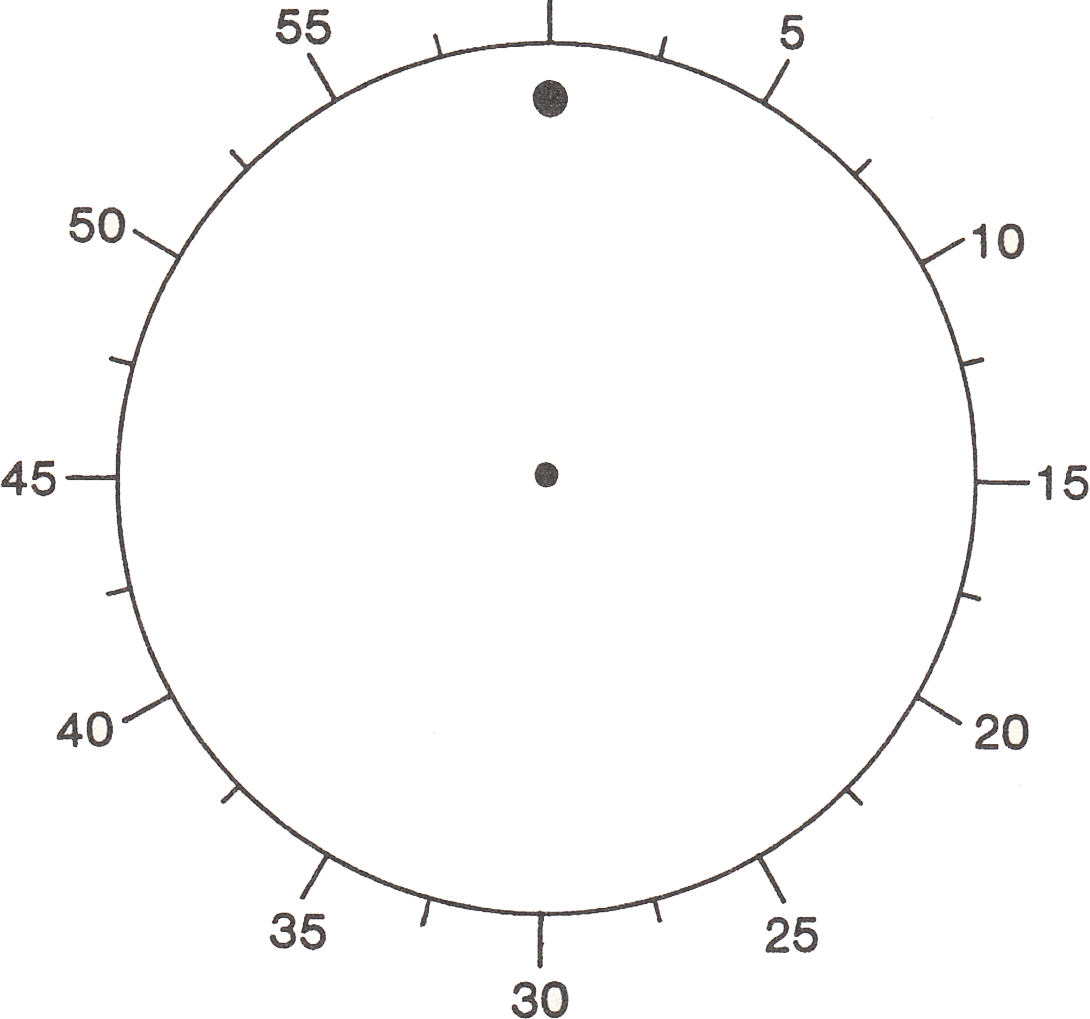


Constant rotation

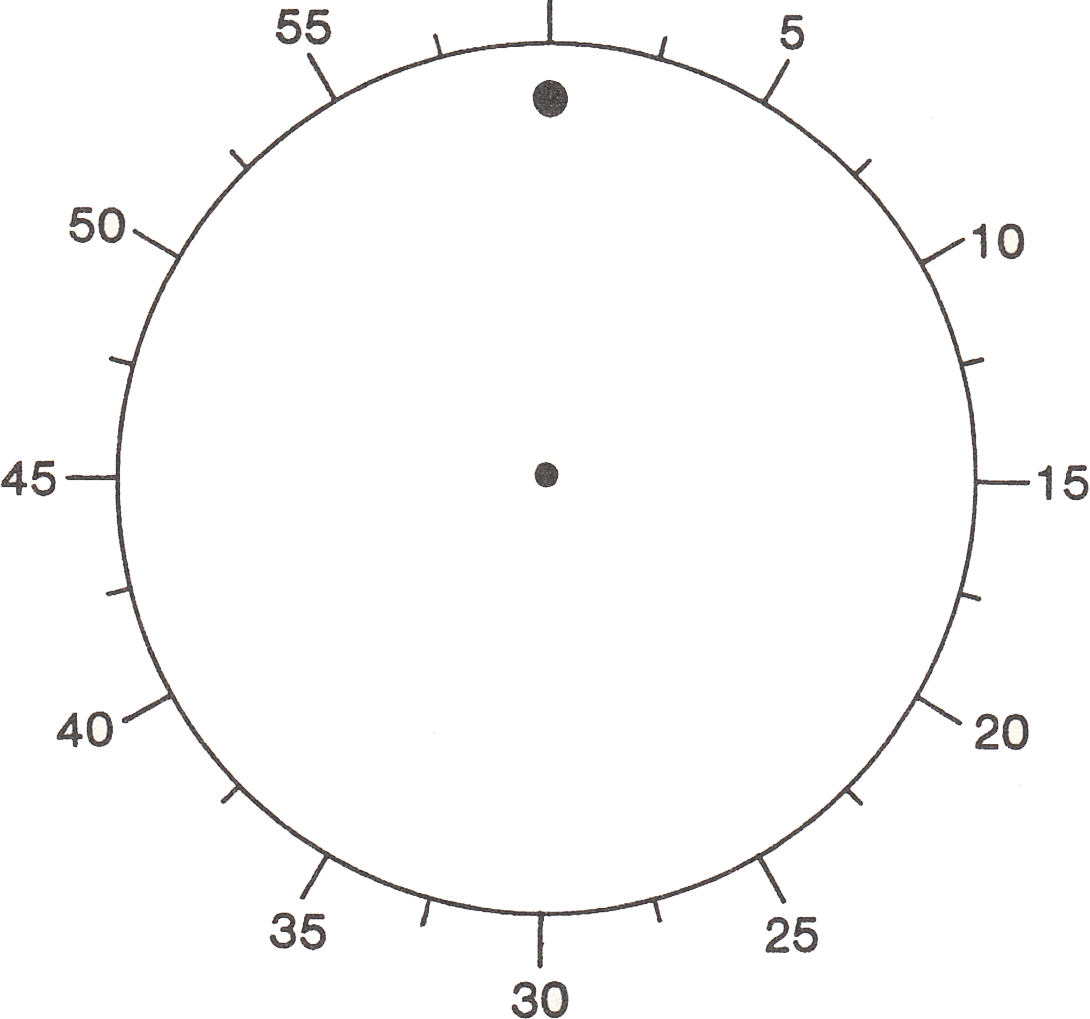
Free key-press

250 ms





 or   



Rotation for some

random time and stops Action judgment Tone

Enter the time when you press the key/heard the tone

Judgment

Enter the letters

***Figure 2*. The procedure in action and tone judgments is the same except asking either the perceived time of the action or the tone. Action produces a tone in some trials, and it does not in others. The probability of action producing a tone depends on the condition targeting predictive or postdictive processes.**

**Analysis**

The analysis mainly focuses on temporal judgments of the actions. As explained above, the judgment of tones is for participants to prevent from ignoring the tone and cause-effect relation of it with the action. Thus, it is not included in the analysis. Participants’ baseline action judgments are subtracted from their mean action judgments. In that way, the measure of binding for action is created. Participants are randomly assigned to one of the cue conditions.

In predictive-cue condition, the trials that the action does not produce an outcome are the main target of the analysis to isolate the predictive mechanisms. In that way, since there is no outcome intentional binding can be used as a measure of a prediction mechanism. Since the probability of action to produce an outcome is 75%, in two blocks of eight the action does not produce an outcome. Therefore, action judgments in one block for low-cognitive load and in one-block of high-cognitive load in prediction-cue condition are compared to each other.

On the other hand, to isolate postdictive cues, trials that produced an outcome while they are in low probability conditions are examined. Since the probability of action to produce an outcome is low, in that way instead of predictive mechanisms constructing the sense of agency before the outcome occurrence, agency can be constructed only after the outcome’s actual occurrence. Since 25% of the time action produces an outcome, two blocks of eight produced an outcome. One of these two is in the low cognitive load task while the other one is in the high-cognitive load task. Thus, action judgments in one block of low-cognitive load and one block of high-cognitive load tasks in postdictive-cue conditions are compared to each other.

Baseline action and baseline tone judgments are subtracted from operant action and operant tone judgments to find the temporal binding without participants’ subjective differences on time perception.

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