Dual Modulation Mechanism of Cognitive Control for the Environmentally Adaptive Behavior

（環境適応行動を導く認知制御の二重変調機構）

HASEGAWA, Kunihiro

（長谷川 国大）

Doctor of Psychology

Graduate School of Environmental Studies, Nagoya University

（名古屋大学大学院環境学研究科　博士（心理学））

2014

Declaration

I hereby declare that the research in this thesis is the author's own original work, and the thesis has not been submitted either in the same or different form, to this or any other University for a degree.

HASEGAWA Kunihiro

Acknowledgements

My heartfelt appreciation goes to Dr. Shin'ya Takahashi whose enormous support and insightful comments were invaluable during the course of my study. I would like to express my gratitude to my current boss Dr. Hiroki Tanabe for his constructive guidance. I would also like to thank Dr. Minoru Karasawa and Dr. Hideki Ohira who gave me invaluable comments. I owe my deepest gratitude to Dr. Kiyoshi Ishii and Dr. Yuji Takeda whose comments made enormous contribution to my work. Finally, I am deeply grateful to my mother for her understanding and sacrifice.

要旨 [Abstract in Japanese]

本論文は，人の環境適応行動の実現に重要な役割を果たすとされている認知制御の変調機構を，一過性変調機構と持続性変調機構が同時並列的に働くシステムとして捉えることで統合的に理解できることを実験的に検証したものである。

第 1 章では，研究対象となる認知制御の変調機構に関する現象と従来の知見が整理され，本研究の検討課題と解決手法が提示された。認知制御とは，環境中の複数の刺激がそれぞれ異なる反応を導くことで生じる競合事態を解消するための認知機能であり，実験室的には，認知的競合課題における適合性効果を指標として検討されてきた。適合性効果とは，課題関連情報と課題無関連情報が異なる反応を駆動する場合 (不適合試行), 両情報が同じ反応を駆動する場合(適合試行) よりも成績が低下する現象を指す。これまで, 認知制御の働きは常に一定ではなく, 環境文脈に応じて柔軟に変調するシステムを持つことが議論されてきた。これは, 適合性効果が, 直前試行における一度の競合の経験 (一過性文脈) あるいは比較的長期にわたる高頻度の競合経験 (持続性文脈) によって変化することから示されてきたが，その変化のメカニズムについては諸説あり合意が得られていない。たとえば，競合検出理論 (Botvinick, Braver, Barch, Carter, & Cohen, 2001) は競合検出と制御水準の変調を繰り返すフィードバックループにより適合性効果の変化を説明するが，具体的に変調される情報処理機構として課題関連情報処理経路の促進を想定する促進説 (Egner & Hirsch, 2005) と，課題無関連情報処理経路の抑制を想定する抑制説 (Stürmer, Leuthold, Soetens, Schröter, & Sommer, 2002) が対立している。また，随伴性学習説(Schmidt, 2013)は，既存の刺激－反応間の結びつきに加え，競合事態の経験により学習される新たな結びつきによって適合性効果の変化を説明する。さらに，特徴結合説 (Hommel, Proctor, & Vu, 2004) では，経験された課題関連情報と課題無関連情報，そして反応出力の 3 特徴がイベントファイルとして一時的に保持され，これらの特徴がすべて繰り返される場合には競合の生起が回避されると主張する。最近では，これらのメカニズムが必ずしも排他的ではなく，それぞれ異なる背景機構により生じている可能性も指摘されている。そこで本研究では，① 二つの情報処理経路 (課題関連経路，課題無関連経路) のうちどちらの経路が変調されるのか，② (①で回答が得られた課題無関連経路が) どのように変調されるのか，③ (②で明らかにされた変調過程は) 意識的な気づきを伴う過程か否か，という三つの検討課題を順次設定し，以降の第 2 章から第 4 章で報告される 5 つの実験を通じて検討が試みられた。

第 2 章では，認知的競合課題の遂行に関わる課題関連情報処理経路と課題無関連情報処理経路という二つの処理系のうち，どちらが一過性変調および持続性変調を引き起こしているかを明らかにするため，課題切り替え手続きを用いた検討が行われた。課題切

り替え手続きでは，二つの異なる認知的競合課題が 1 試行ずつ交互に実施されるが，この 2 課題に共通する課題属性を課題関連情報 (関連条件) または課題無関連情報 (無関連条件) のいずれかに設定し，課題遂行における適合性効果の変調の程度が比較された。関連条件では課題関連情報は同じで課題無関連情報が異なる 2 課題が組み合わされた。したがって，課題関連情報処理経路で変調が生じているのであれば，これを共有する 2 課題間に変調の影響が及ぶと予想された。一方，無関連条件では課題関連情報が異なり課題無関連情報は同じ 2 課題が組み合わされた。したがって，課題無関連情報処理経路で変調が生じているのであれば，これを共有する 2 課題間に変調の影響が及ぶと予想された。以上の条件比較を，実験 1 では一過性変調，実験 2 では持続性変調の実験文脈でそれぞれ検討した。すなわち実験 1 では，組み合わせる 2 課題の適合試行と不適合試行の出現比率を等しくした上で，直前試行 (分析対象外課題) の試行タイプ別に分析対象課題の成績が分析された。実験 2 では，分析対象外課題の試行タイプがセッション内ですべて適合試行，もしくはすべて不適合試行とされ，セッション内での適合試行／不適合試行の比率を不均等に操作した場合の分析対象課題の成績が比較された。実験の結果，実験 1，実験 2 ともに，分析対象課題の成績 (適合性効果) に影響が見られたのは無関連条件のみであった。したがって，一過性変調と持続性変調ともに課題無関連情報処理経路で変調が生じていることが示された。

第 3 章では課題無関連情報処理経路がどのように変調されているかが検討された。先行研究において，課題無関連情報処理経路の変調機構として，競合検出理論における経路の抑制強化と随伴性学習という二つの説明が提起されていた。本研究では，サイモン課題に一定割合で挿入される No-Go 試行における虚警報 (False Alarm; FA) 反応を指標として，実験 3 で持続性文脈，実験 4 で一過性文脈における変調が，それぞれ上記のいずれの説明とより整合するかを検討した。サイモン課題では，通常，提示される刺激の非空間情報を課題関連情報，空間情報を課題無関連情報とした上で空間的反応が求められるが，No-Go 試行では課題無関連情報のみが与えられるため，実験参加者は反応そのものを抑制しなければならない。ここで，もし課題無関連情報処理経路の抑制が強化されていれば，No-Go 試行における誤反応である FA 反応の発生頻度が低下すると予想された。一方，随伴性学習により課題関連情報と反応の間の新たな結びつきが学習されていれば，学習された結びつきに基づく特異な FA 反応が見られると予想された。結果より，持続性文脈の効果を検討した実験 3 では FA 反応の頻度低下は見られず，画面右に提示された刺激に対する左手の反応など，通常はみられない FA 反応が多く生じた。これは随伴性学習を支持する結果であった。一方，一過性文脈の効果を検討した実験 4 では，適合試行直後に比べ不適合試行直後の FA 反応は少なく，課題無関連情報処理の抑制強化が支持された。したがって，一過性文脈に対しては課題無関連情報処理経路の抑制強化，持続性文脈に対しては随伴性学習による新しい経路の学習という，異なる適応的変調シス

テムの存在が示唆された。

第 4 章では一過性変調と持続性変調における意識的気づきの役割が検討された。競合検出理論では競合に対する気づきが引き金となって後の制御変調を導くとする一方，随伴性学習では最終的に出力された反応と刺激の関係が無意識的に学習されるとする。そこで実験 5 では，閾下プライミングを用いた認知的競合課題により，競合への気づきが生じない事態における一過性文脈および持続性文脈の影響が検討された。その結果，一過性変調効果は見られなかったが，持続性変調効果は見られた。これは，第 3 章で導かれた一過性変調は競合検出による経路抑制強化，持続性変調は随伴性学習に基づくとする考えを支持する結果であった。

最後に第 5 章では，第 2 章から第 4 章までの実験的検討から得られた知見を総括した上で，これに基づく認知制御の二重変調機構モデルが提示され，その機能的意義が議論された。実験的検討より，一過性変調の基盤としての競合検出および経路抑制強化，持続性変調の基盤としての随伴性学習が示されたことから，これらが並列的に働く二重変調機構が想定された。これにより，既存の刺激反応経路が適応的に働かなくなるような大きな環境変化に再適応する仕組みを備えると同時に，持続的な環境変化を伴わない偶発的な競合事態には既存の刺激反応経路を維持したまま一時的に適応することが可能になると考えられた。一方で，本研究では認知的競合課題として主としてサイモン課題を用いてきたため，他の課題事態を含めた知見の一般化可能性の検討が必要であることなどが今後の課題として議論された。

Contents

List of Tables

List of Figures

Chapter 1 Introduction

1.1 Preface

Despite the abundance of information in our daily environment, we use only a small amount of it for our adaptive behaviors. Hence, proper selection of necessary information is very important. Creating an automatic response is a reasonable strategy for proper selection because it saves much cognitive effort. Unfortunately, however, this automated process is not always valid. For example, if an individual wants to push a button on his/her right side, he/she would automatically reach with his/her right hand. However, when the right hand is injured or busy, he/she may have to use the left hand instead, consequently generating conflict. Cognitive control is a function for resolving such a conflict. In a conflict situation, cognitive control plays an important role to inhibit the automatic response and facilitate controlled selection (Monsell & Driver, 2000).

1.2 Cognitive Control and Resolution of Cognitive Conflict

Cognitive control is evaluated through participants' performance in a cognitive conflict task, in which a stimulus has two attributes, and participants respond based on either attribute. For example, in the Simon task (Lu & Proctor, 1995), participants are required to make a spatial response (e.g., press a response key with their left or right hand) to the non-spatial attribute of a stimulus (e.g., its color, such as red or green). A stimulus also has spatial information (e.g., being presented on the left or right side of a screen). Therefore, this task requires participants to respond to the stimulus color (task-relevant information) while ignoring the stimulus location (task-irrelevant information). Provided that the response for the red stimulus was assigned to the left hand, the reaction time (RT) would be shorter when the red stimulus is presented on the left side (congruent trial) than the right side (incongruent trial). That is, RT is influenced by the congruency between the task-relevant information (stimulus color that defines the responding hand) and the task-irrelevant information (stimulus location that is irrelevant to the response). Thus, the difference between performances in a congruent and an incongruent trials is called the "congruency effect" (Figure 1).

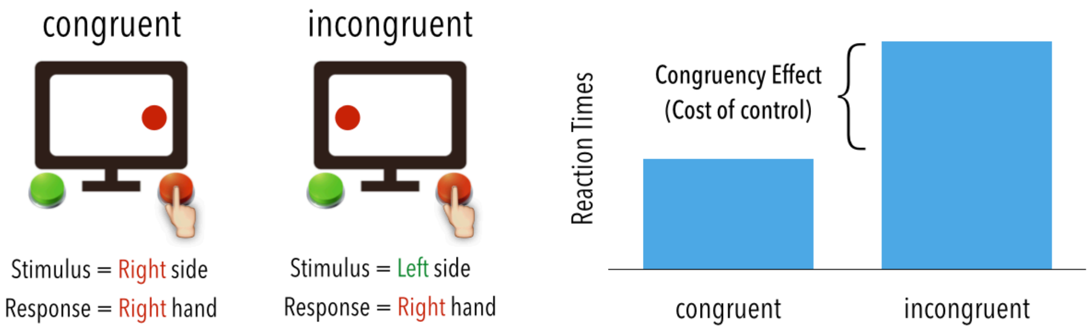

Figure 1 Schematic illustrations of the Simon task and the congruency effect.

1.2.1 Dual Route Model of Conflict Resolution

In previous studies, the conflict resolution mechanism was explained by the dual route model (Kornblum, Hasbroucq, & Osman, 1990). Let's take an example shown in Figure 2; a green stimulus is presented on the right side of the screen, when green color is assigned to a response by the left hand as the task-relevant stimulus feature.

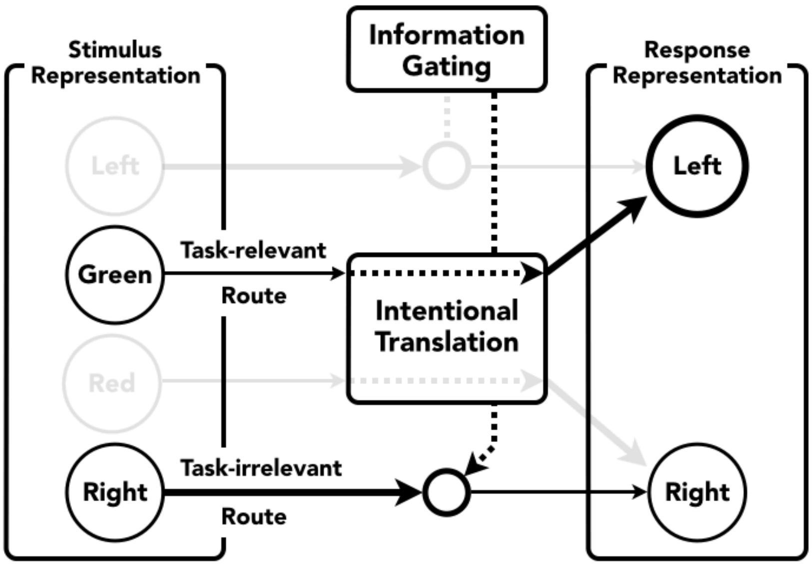

Figure 2 Basic structure of dual-route models of conflict resolution in the cognitive conflict task (Hommel, Proctor, & Vu, 2004). Broken lines indicate the intentional processes and straight lines indicate the automatic processes.

First, at the stimulus input, representation of the stimulus color (green) and representation of the stimulus location (right side) are assumed to be activated in parallel (*Stimulus Representation*). Next, these stimulus representations activate the representation of a responding hand (*Response Representation*) based on the strength of linkage between units at each representation level. Notice that the strength of linkage is assumed to be in a "degree" manner, which is depicted as the relative line width. The certain stimulus representation is strongly associated with the certain response representation. For example, a stimulus location automatically activates a spatial response (e.g., stimulus presented on the right side of a screen activates key-pressing by the right hand). This is called the *spatial-stimulus response compatibility* (Fitts & Seeger, 1953; Simon, Sly, & Vilapakkam, 1981). On the other hand, a non-spatial stimulus feature must be intentionally translated to a spatial response feature according to the task instruction, since it has no association with the spatial response feature. In the cognitive conflict task in which the automaticity of responding for the task-irrelevant information is higher than that for the task-relevant information, response selection should not depend on such automaticity. In the case of Figure 2, green color representation is translated into left hand response according to the task instruction (*Intentional Translation*), whereas right-side representation (at least initially) has stronger linkage with right hand response than with left hand response based on lateral automaticity, thereby generating conflict. Therefore, response activation based on the task-irrelevant route need to be inhibited in advance. Representation of the right hand response, mainly activated by the right-side stimulus location, must be properly inhibited so that representation of the left hand response triggers response by the left hand (*Information Gating*). Finally, response is made by either hand according to the relative strength of the *Response Representation*.

According to this model, conflict resolution is needed in the incongruent trial. In contrast, it is unnecessary when the task-relevant and task-irrelevant information trigger the same response in the congruent trial (e.g., left hand key-pressing activated by both the left location and the red color of the stimulus). Consequently, the congruency effect is considered to show the activation level of the cognitive control processes.

1.3 Modulation of Control Demand Based on the Environmental Context

It is recognized that the congruency effect decreases when a congruent/incongruent trial is immediately preceded by an incongruent trial relative to when preceded by a congruent trial (Gratton, Coles, & Donchin, 1992) (Figure 3). This is called the *conflict adaptation*, or the *Gratton effect*. This transient modulation of cognitive control is regarded as an adaptation to the trial-by-trial context.

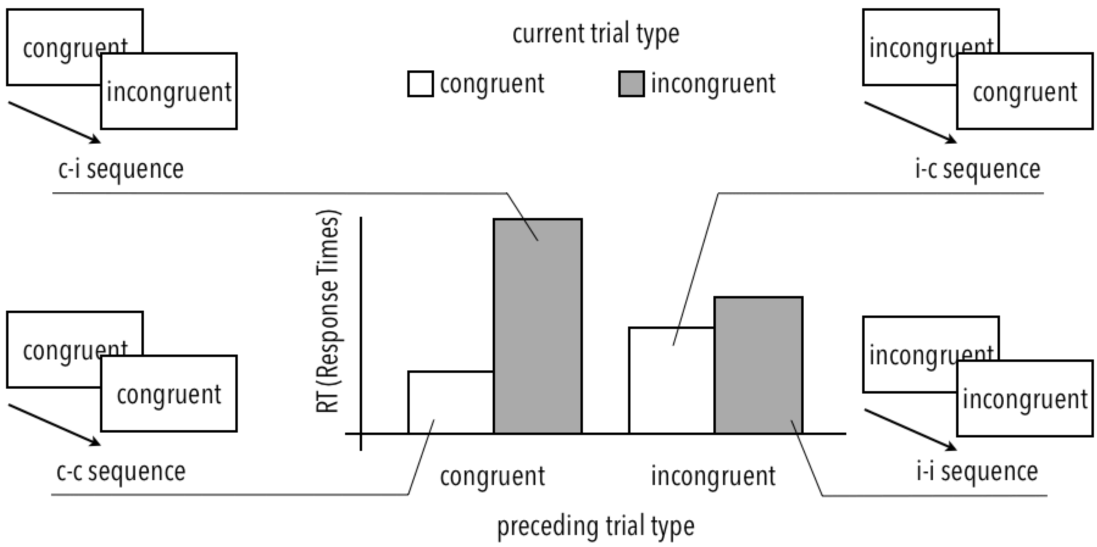

Figure 3 Schematic depiction of the Gratton effect. RT in i-i sequences (an incongruent preceding trial followed by an incongruent test trial) was shorter than that in c-i sequences (a congruent preceding trial followed by an incongruent test trial). On the other hand, RT in i-c sequences (an incongruent preceding trial followed by a congruent test trial) was shorter than that in c-c sequences (a congruent preceding trial followed by a congruent test trial).

In addition to the effect by transient (trial-by-trial) context, sustained (block-wise) context is also known to influence the congruency effect. This is called the *conflict context effect* or the *proportion congruency effect*. The congruency effect tends to be smaller in an experimental block containing a larger number of incongruent trials than in a block with a larger number of congruent trials (Gratton et al., 1992). Furthermore, in such an experimental design with extremely large proportion of incongruent trials, the congruency effect has been shown not only to disappear but also to reverse (Lindsay & Jacoby, 1994; Logan & Zbrodoff, 1979). In this case, known as the reverse congruency effect, RT on the congruent trials becomes longer than RT on the incongruent trials.

Furthermore transient and sustained changes have been shown in other cognitive conflict tasks than the Simon task, such as the Stroop task (Kerns et al., 2004) and the Flanker task (Gratton et al., 1992). That is, these contextual changes of the congruency effect should be considered as a general function in the cognitive control.

In summary, human does not always passive to the conflict situation; rather, cognitive control seems to be actively modulated depending on the situation. In previous studies, the modulation mechanism has been drawn attention to as a key function for the human flexible behavior (Monsell & Driver, 2000). In the next section, hypothetical models of such mechanism proposed in previous studies are discussed.

1.4 Hypothetical Models of Control Modulation

1.4.1 Conflict Monitoring Theory

Conflict monitoring theory (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Botvinick, Cohen, & Carter, 2004) provides a major account of these control modulations. According to this theory, these changes reflect conflict-driven adaptation of the cognitive control process, and detection of conflict in the incongruent trials enhances the cognitive control process, thereby weakening the congruency effect after incongruent trials (Figure 4).

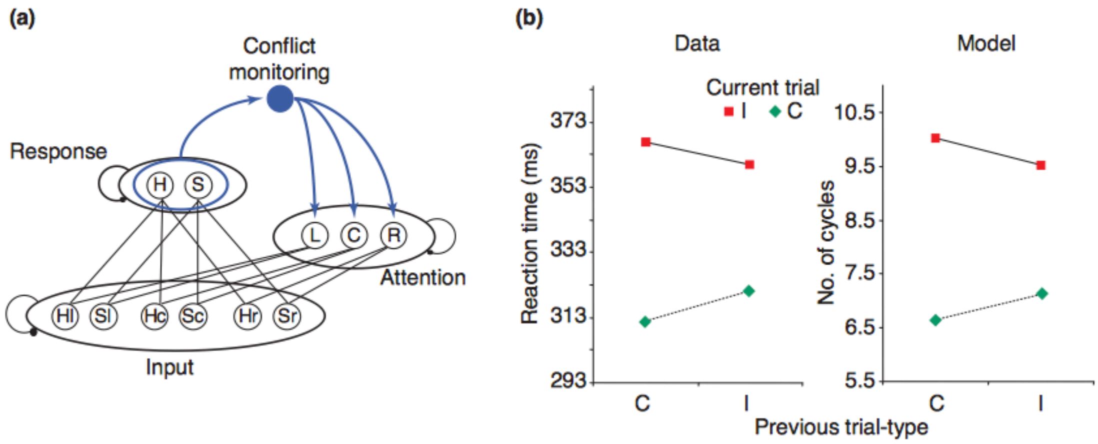

Figure 4 Schematic depiction of confluct monitoring theory; taken from Botbinick et al. (2004). a) A neural network implementation of conflict monitoring in the flanker task (Botvinick et al., 2001). In the base model (shown in black), target and flanker inputs send activation to a response layer, and attention units bias processing towards the target input. Conflict in the response layer leads to activation of a conflict-monitoring element (blue), which, in turn, modulates activity of the attention units. Redrawn with permission from Cohen et al. (1992). b) Performance is more focused on the target item (less influenced by the flankers, so response is faster) on trials following incompatible trials, both in human performance (left; data redrawn with permission from Gratton et al. (1992) and in the conflict-monitoring model (right; data redrawn with permission from Botvinick et al. (2001).

Some functional magnetic resonance imaging (fMRI) studies support the conflict monitoring theory, showing that the anterior cingulate cortex (ACC) and the dorsolateral prefrontal cortex (DLPFC) are activated when incongruent trials are performed. It is assumed that the activation of ACC reflects the work of conflict monitoring, and the activation of DLPFC reflects the modulation of cognitive control (Botvinick, Nystrom, Fissell, Carter, & Cohen, 1999; Egner, 2007; Kerns et al., 2004; MacDonald, Cohen, Stenger, & Carter, 2000).

An important question here is what type of process is enhanced by the control demands. Some researchers argue that contextual modulation of the congruency effect is caused by the enhanced facilitation of the task-relevant process (Egner & Hirsch, 2005; Notebaert & Verguts, 2008), while others argue that it shows enhanced inhibition of the task-irrelevant process (Stürmer, Leuthold, Soetens, Schröter, & Sommer, 2002; Wendt, Kluwe, & Peters, 2006).

1.4.1.1 *Facilitation Account: Boosting of the Task-relevant Route*

The facilitation account considers that the contextual change of congruency effect reflects an attention shifting. According to this, control modulation acts task-relevant process. Egner and Hirsh (2005) reported that conflict monitoring guided a specific amplification of the cortical area that was responsible for the task-relevant process. In this research, a variant of the Stroop task was used (a famous person's face and the name were combined) while recording hemodynamic responses from human visual cortex specialized for face processing.

As a result, in response to high conflict, cognitive control mechanisms enhanced performance by transiently amplifying cortical responses to task-relevant information rather than by inhibiting responses to task-irrelevant information. These results implicated attentional target-feature amplification as the primary mechanism for conflict resolution through cognitive control (Figure 5).

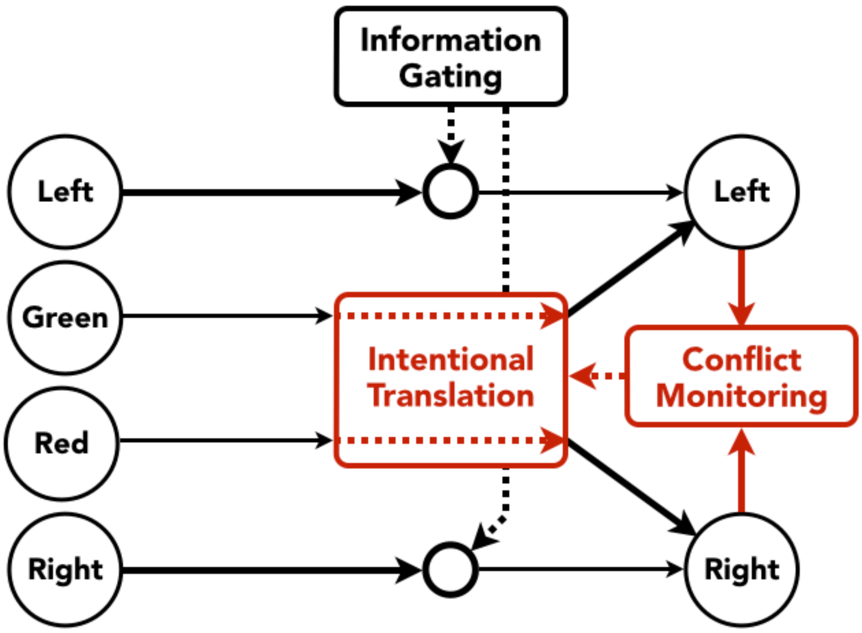

Figure 5 Schematic illustration of facilitation account of the conflict monitoring theory. Red indications show modulated processes: attention shifting to task-relevant route and enhancement of intentional translation.

1.4.1.2 Inhibition Account: Gating of Task-irrelevant Route

On the other hand, the inhibition account considers that the contextual change of congruency effect reflects a gating of the task-irrelevant route. Stürmer and colleagues (Stürmer et al., 2002) used the lateralized readiness potential (LRP) as a measure of selective motor preparation in the Simon task. LRP is an event-related brain potential at the surface of the brain that is thought to reflect the preparation of motor activity on a certain side of the body. Generally, incorrect motor preparation was activated on incongruent trials in the Simon task. Actually, Stürmer et al. observed such potential when the preceding trial was congruent, but did not when the preceding trial was incongruent. This suggests that the experience of conflict situation boosts the inhibition of location (task-irrelevant information) -based response activation. That is, the control modulation reflects closing of the gate at the task-irrelevant route (Figure 6).

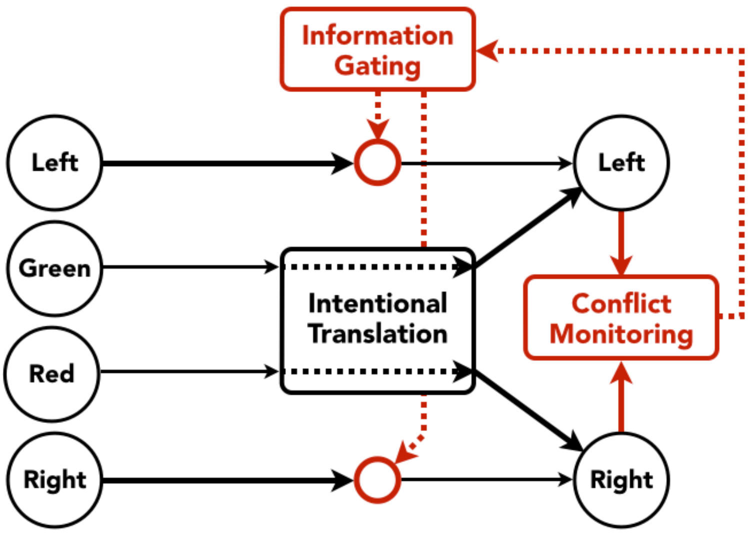

Figure 6 Schmatic illusitration of inhibition account of the conflict monitoring theory. Red indications show modulated processes: enhancement of intentionally gating in task-irrelevant processing route.

1.4.2 Contingency Learning and Item-specific Proportion Congruent Effect

Some recent studies have provided several difficulties for the conflict monitoring theory.

Among these, the item-specific proportion congruent (ISPC) effect (Jacoby, Lindsay, & Hessels, 2003) indicates the other aspect of cognitive control different from the conflict monitoring.

For instance, in the Stroop task, a color word was presented most often in congruent color (mostly congruent items; e.g., a word BLUE is presented in blue) and other words were presented most often in incongruent color (mostly incongruent items; e.g., a word RED is presented in green). Then the congruency effect was smaller in mostly incongruent items than in mostly congruent items, regardless high and low proportion congruenct items were intermixed and participants could not know the manipulation. This local level effect cannot be explained by central task-demand modulation at a general level (e.g., conflict monitoring theory).

The contingency learning account (Deroost, Vandenbossche, Zeischka, Coomans, & Soetens, 2012; Musen & Squire, 1993; Schmidt, 2013) proposes a reasonable explanation of this effect. According to this account, pairings of a particular color name with particular colors may lead to associations between color words and responses in unconsciously. Therefore, this was interpreted that task-irrelevant color words was associated with the correct response in the mostly incongruent items, consequently the congruency effect was decreased (Figure 7).

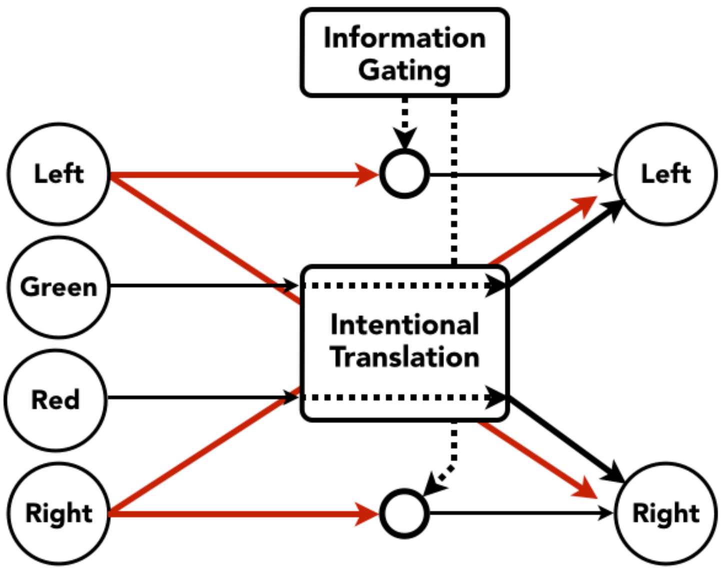

Figure 7 Schematic illustration of the contingency learning theory. Red indications show modulated processes: unintentionally association learning between a task-irrelevant stimulus feature and a response feature.

1.4.3 *Feature Binding from the Event File and Repetition Priming Effect*

Hommel et al. showed that partial repetitions incur a significantly greater cost on RT than do complete changes and complete repetitions (Hommel et al., 2004). This pattern of feature overlap effects is consistent with the feature integration account (Hommel, 1998; Hommel et al., 2004) and can account for sequential (trial-by-trial) modulation. According to the feature integration account, sequential effect is due to an additional mechanism that is responsible for building integrated representations of S–R episodes, or event files (Figure 8A). This feature integration mechanism binds the stimulus feature and the response feature on a given trial into an event file, which remains integrated at least until the next trial. On the next trial, if some of the S–R features repeat but others change (e.g., the same stimulus, but at the opposite location), the repeating features activate the remaining (nonrepeating) features in the event files, which creates stimulus and/or response conflict. Consequently, RT on partial-repetition trials is lengthened. On the other hand, if all of the features repeat (complete repetitions) or change (complete change) from the preceding trial, there is no interference by the previous event file, and performance would be faster (conjunction benefits; Figure 8B).

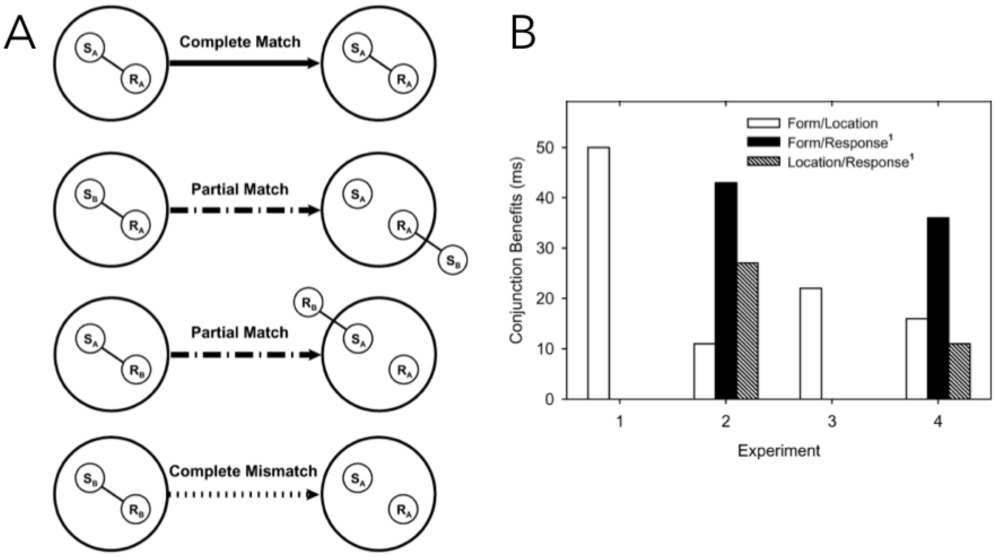

Figure 8 A: The four possible combinations resulting from the repetition or alternation of binary stimulus and response features (Hommel et al., 2004). B: Conjunction benefits (RT partial match - RT complete match/mismatch).

1.4.4 Summary of Hypothetical Models in Previous Studies

Table 1 shows the summary of hypothetical models discussed above. There are three distinctive aspects that characterize each model's explanation for the modulation process; 'where does the modulation occur,' 'what is modulated,' and 'how does it modulated?' First, as for 'where' aspect, the conflict monitoring theory is still controversial; the task-relevant route is assumed by the facilitation account, while the task-irrelevant route is assumed by the inhibition account. Contingency learning assumes the association learning between stimulus feature and response feature in the task-irrelevant route. Feature binding would consider both routes, though not explicitly argued. Second, as for 'what' aspect, the facilitation account assumes amplification of the task-relevant route, whereas the inhibition account assumes suppression of the task-irrelevant route. In contrast with them, contingency learning and feature binding argue different mechanisms from amplification/suppression of existing routes; that is, creation of a new route via association learning between stimulus feature and response feature, and utilization of an event file from the preceding trial, respectively. Finally, as for 'how' aspect, accounts based on the conflict monitoring suppose voluntary control, whereas contingency learning and feature binding suppose involuntary, unconscious processing.

Table 1 Summary of hypothesized models.

	Where?	What?	How?
Conflict Monitoring			
Facilitation Account	Task-relevant Route	Route Amplification	Voluntary
Inhibition Account	Task-irrelevant Route	Route Suppression	Voluntary
Contingency Learning	Task-irrelevant Route	Creating a New Route	Involuntary
Feature Binding	Both	Using an Event File	Involuntary

1.5 The Issues of the Present Study

A critical, but unsettled, question is whether the transient and sustained modulations are caused by the same underlying mechanism. According to the conflict monitoring theory, the transient modulation is achieved by conflict monitoring on a trial-by-trial basis as described above, and the sustained modulation is regarded as an accumulation of such a transient effect. However, recent studies emphasize that these two types of contextual modulations have different mechanisms (Braver, 2012; De Pisapia & Braver, 2006; Funes, Lupiáñez, & Humphreys, 2010; Ridderinkhof, 2002). According to these dual control accounts, the control modulation for transient trial-by-trial sequence is explained as an enhancement of inhibition of the task-irrelevant process; micro-adjustment (Ridderinkhof, 2002) or reactive-control (Braver, 2012; De Pisapia & Braver, 2006). On the other hand, the control modulation for sustained conflict context is explained as boosting of the task-relevant process; macro-adjustment (Ridderinkhof, 2002) or proactive-control (Braver, 2012; De Pisapia & Braver, 2006).

1.5.1 Facilitation of Relevant Route vs. Inhibition of Irrelevant Route

An important question here is what type of process is enhanced by the control demands. To solve this controversy, a task-switching paradigm is useful to examine which task-relevant or -irrelevant process is modulated (Fernandez-Duque & Knight, 2008; Funes et al., 2010; Notebaert & Verguts, 2008). In this paradigm, two different tasks run alternately in each trial, one being treated as a test task and the other as a preceding task. Task-relevant and task-irrelevant attributes of stimuli in these tasks can be independently manipulated; thus, by manipulating the similarity of stimulus attributes between two tasks, it is possible to determine which process, facilitation or inhibition, is affected by experiencing the conflict. If contextual modulation occurs because of the enhanced facilitation of the task-relevant process, it would appear only when the stimuli of the preceding task and the test task have the same task-relevant attributes. In contrast, if contextual modulation is caused by the enhanced inhibition of the task-irrelevant process, it would appear only when the stimuli of the two tasks have the same task-irrelevant attributes.

In addition to this "relevant vs. irrelevant" problem, another important question is whether the underlying mechanisms of transient and sustained modulations are the same. As mentioned above, the conflict monitoring theory regards sustained modulation as an accumulated effect of transient modulation (Botvinick et al., 2001; 2004), thereby implying that these two types of modulations essentially share the same mechanism. However, some researchers question this view by arguing difference, rather than similarity, between these modulations (Fernandez-Duque & Knight, 2008; Funes et al., 2010; Mayr & Awh, 2009). To date, this problem has not been resolved because evidence for both the same-side and the difference-side is limited and insufficient.

Based on the above arguments, the empirical studies described in Chapter 2 was conducted with two aims: first, to reveal whether conflict adaptation is caused by the modulation of the task-relevant or the task-irrelevant processes, and second, to examine the differences between transient and sustained modulations. By using the same task-switching paradigm, Experiment 1 examined transient modulation and Experiment 2 examined sustained modulation.

1.5.2 Conflict Monitoring vs. Contingency Learning

The important behavioral evidence that suggests different mechanisms between the sustained and transient modulations is the aforementioned reverse congruency effect. The reverse congruency effect generated by the sustained context cannot be explained by any idea based on accumulation of the effect generated by the transient context (Botvinick et al., 2001; 2004) or boosting of the task-relevant process (macro-adjustment/proactive-control) (Braver, 2012; De Pisapia & Braver, 2006; Ridderinkhof, 2002). This is because, regardless of how much the task-relevant process was enhanced, the congruency effect would not reverse. Similarly, if the task-irrelevant process was completely inhibited, then the response should be activated only by the task-relevant feature in both the congruent and incongruent trials, which means that these trial types no longer have different features (i.e., task-irrelevant information) to process; this would result in no congruency effect, not the reverse congruency effect.

To explain the reverse congruency effect, we need an idea that regards the sustained effect as more than simple accumulation of the transient effect. The contingency learning account, which was originally advocated for the Stroop task (Schmidt, 2013; Schmidt & Besner, 2008), may be one convincing explanation for the Simon task as well. This account explains the sustained conflict context effect in terms of the utilization bias of the task-irrelevant information based on the contingency learning of association between the task-irrelevant information and the response mapping.

Therefore, in Chapter 3, we focused on processing of the task-irrelevant information during the sustained modulation, which has not been extensively examined by previous studies. Specifically, we aimed to obtain evidence that indicates an active utilization of the task-irrelevant information when the reverse congruency effect is observed. For instance, in the Simon task, under the condition in which an experimental block contains an extremely large proportion of incongruent trials, a potential reactive bias toward responding with the hand opposite to the stimulus location may be generated as a result of experiencing a number of incongruent trials. This in turn may result in the reverse congruency effect, since such a response bias is more advantageous to the incongruent than to the congruent trials.

To demonstrate the response bias that may reflect active utilization of the task-irrelevant information, we examined false alarm (FA) responses on no-go trials within the Simon task. Participants were instructed to respond to a red or green stimulus by pressing corresponding keys, while ignoring the presentation side of the stimulus, which may agree or disagree with the side of the key to be pressed (i.e., the hand to be used). In addition to these trials comprising the typical Simon task, no-go trials were included, on which a gray stimulus was presented on the left or right side of a screen, and participants are not required to press any keys. Thus, the no-go stimulus contains information about the stimulus location but not about stimulus color that defined the hand to be used. If the response bias to the side opposite to the stimulus location was involved in generation of the sustained modulation, then the biased response, which would emerge as an FA on no-go trials, should probably be elicited from the hand opposite to the stimulus side when the block contain a larger number of incongruent trials. Thus, we examined the type of FA responses (same and opposite) on no-go trials as well as overall FA rates and the RTs on normal Simon trials (congruent and incongruent trials) in two experiments in which the sustained and transient contexts were manipulated.

In addition, the feature binding account (Akçay & Hazeltine, 2007; Hommel et al., 2004) should be considered here. It states that RT on the partial repetition trials (in a condition where repetition applies either to a task-relevant stimulus feature corresponding to a required response or to the stimulus location) is likely to be longer than RT on the complete change trials (both the task-relevant stimulus feature and the stimulus location are changed) and complete repetition trials (both the task-relevant stimulus feature and the stimulus location are repeated). We would be able to assume that this effect is not critical for the no-go trials highlighted in the present study, because no-go stimulus has no task-relevant feature and thus the repetition from the preceding trial can be possible only for its location. Nevertheless, for more elaborated discussion, we conducted additional analyze using data of the complete change no-go trials only, and compared them with those of all (complete change and partial repetition) no-go trials.

1.5.3 Voluntary Control Modulation vs. Involuntary Optimization

To understand different kinds of modulation mechanisms, recent studies have highlighted two issues: difference between the block-wise and the trial-by-trial modulations (Ridderinkhof, 2002) and the role of participant's awareness in these modulations (Desender & Van den Bussche, 2012). Especially, though the effect of block-wise adaptation has been often argued as a conscious control (Fernandez-Duque & Knight, 2008), there is no direct evidence supporting the role of awareness for cognitive control in the response conflict task.

As for the block-wise adaptation, previous findings on word recognition give us a clue for revealing the role of awareness. The *masked repetition priming effect* was reported (Bodner & Masson, 2001), which shows the priming effect in the word recognition task is larger when the repetition proportion is high (including 80% word and 20% non-word primes) than low (including 20% word and 80% non-word primes). This effect of the sustained context was repeatedly shown by other researches (Bodner & Dypvik, 2005; Bodner & Masson, 2003; 2004; Kinoshita, Forster, & Mozer, 2008). These evidences suggest unnecessity of awareness in the block-wise adaptation for stimulus identification (e.g., word recognition). However, it is still unclear whether the same thing would apply to the cognitive control for the response conflict as well.

On the other hand, there are some investigations of the role of awareness for the trial-by-trial modulation in the response conflict task, but results are not constant. Kunde showed the absence of trial-by-trial modulation in the subliminal response conflict task (Kunde, 2003). In this study, a task-irrelevant priming arrow was presented for 14 msec before the presentation of the target arrow, which ensured that the pointing direction of the priming arrow was not discriminable. As the results, on incongruent trials (the priming arrow pointed to the opposite direction to the target arrow), reaction time (RT) was longer and the percentage of errors (PE) was larger than on congruent trials (both arrows pointed to the same direction). Moreover, this congruency effect was unaffected by a trial sequence. However, more recent studies using the same task showed the trial-by-trial modulation of PE (Francken, Gaal, & de Lange, 2011; van Gaal, Lamme, & Ridderinkhof, 2010) and RT (van Gaal et al., 2010). These conflicting results show that the role of awareness on the trial-by-trial modulation has not solved yet. Therefore, in Chapter 4, the roles of awareness in the block-wise and trial-by-trial modulations were examined.

1.5.4 Rationale for the Present Thesis

As discussed above, the conflict monitoring theory is considered to be the mostly powerful model at the present for explaining the transient modulation, but not for explaining the sustained modulation. Therefore, for further understanding of the nature of our cognitive control, it is necessary to answer the questions concerning possible differences between the transient and the sustained modulations. Furthermore, to achieve this aim it is unavoidable to convincingly explain the reverse congruency effect.

In the present thesis, differences between transient and sustained modulations of cognitive control were investigated through five experiments. In Chapter 2, Experiments 1 and 2 examined whether conflict adaptation is caused by the modulation of the task-relevant or the task-irrelevant routes by using the task-switching paradigm. Then, in Chapter 3, Experiments 3 and 4 examined mechanism responsible for the reverse congruency effect by analyzing false alarm responses on no-go trials. Through these experiments, the validity of conflict monitoring theory and contingency learning account was tested in transient and sustained modulations. Next, in Chapter 4, Experiment 5 investigated the role of awareness in transient and sustained modulations using subliminally response priming task. Finally, in the general discussion, obtained findings were reviewed together to propose a hypothetical model that explains the transient modulation and the sustained modulation integrally. Implications and limitations of the present study were discussed.

Chapter 2
Facilitation of Relevant Route vs. Inhibition of Irrelevant Route

2.1 Experiment 1

Experiment 1 examined whether the transient context affects the task-relevant and/or the task-irrelevant processes. For this purpose, two conditions, a Relevant condition and an Irrelevant condition, were employed. In the Relevant condition, we combined color-word and color-location tasks, which were run alternately in each trial. These tasks have the same task-relevant information (color) and different task-irrelevant information (word or location). Therefore, if transient modulation is shown, it suggests that the transient context affects the task-relevant process. In contrast, in the Irrelevant condition, we combined the orientation-location and color-location tasks, which were run alternately in each trial, similar to that in the Relevant condition. These tasks have the same task-irrelevant information (location) and different task-relevant information (orientation or color). Therefore, if transient modulation is shown in this situation, it suggests that the transient context affects the task-irrelevant process.

2.1.1 Method

2.1.1.1 Participants

Eighteen volunteers (14 women and 4 men; 19–30 years of age, $M = 23.2$) participated in the experiment. All volunteers reported having normal or corrected-to-normal vision and were not familiar with the purpose of the experiment. All participants performed the tasks under both the Relevant and Irrelevant conditions, with their order being counterbalanced. All participants provided written informed consent. They gave permission to use their data in the analysis.

2.1.1.2 Apparatus and Stimuli

Stimuli were generated by MATLAB (MathWorks) and Psychophysics Toolbox (Brainard, 1997) and displayed on a CRT monitor (GDM-F520, Sony), which was controlled by a computer (MB324J/A, Apple). The viewing distance was 95.5 cm.

The color-word task and the orientation-location task were employed as the preceding tasks in the Relevant and Irrelevant conditions, respectively. The color-location task was employed as the test task in both the Relevant and Irrelevant conditions. In the color-word task, four stimuli were created by combining two words (ao [blue] and kiiro [yellow]) and two font colors (blue and yellow). The words were presented in Japanese hiragana letters on the center of the monitor. A single letter had a 1° visual angle. In the orientation-location task, a vertical or a horizontal white bar (0.1° × 1°) was displayed either on the left or the right side (3° away from the center) of the monitor. In the color-location task, a red or green disk (1° diameter) was displayed either on the left or the right side (3° away from the center) of the monitor. In all tasks, the background color was black.

2.1.1.3 Design and Procedure

In the color-word task, participants were asked to respond to the color of the word while ignoring its meaning (color name) by pressing the “c” key on the keyboard with their left index finger for blue and the “m” key with their right index finger for yellow (Figure 9A). In the orientation-location task, participants were asked to respond to the orientation of the bar while ignoring its position on the monitor by pressing the “c” key for the vertical bar and the “m” key for the horizontal bar (Figure 9B). In the color–location task, participants were asked to respond to the color of the disk while ignoring its position on the monitor by pressing the “c” key for the green disk and the “m” key for the red disk (Figure 9C). These stimulus response mappings were the same for all participants.

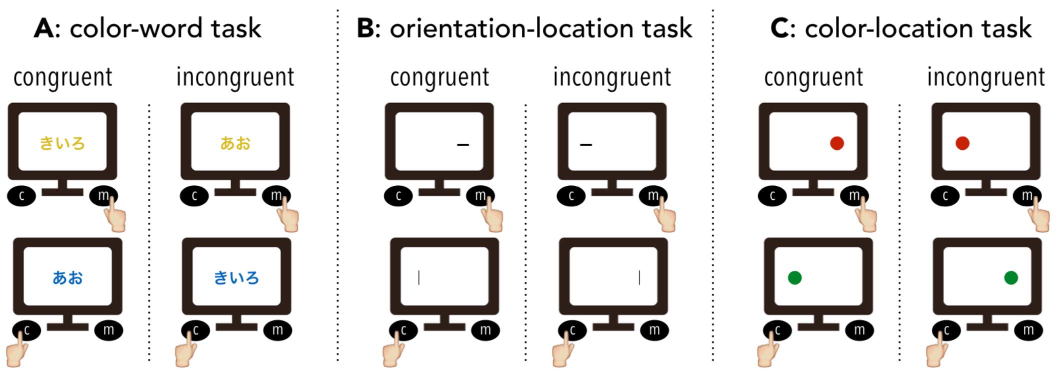

Figure 9 A: color-word task. B: orientation-location task. C: color-location task.

In the Relevant condition, the preceding task was the color-word task, which included 80 congruent trials (ao presented in blue or kiiro in yellow) and 80 incongruent trials (ao presented in yellow or kiiro in blue). The test task was the color-location task, which included 80 congruent trials (a green disk presented on the left side or a red disk on the right side) and 80 incongruent trials (a red disk presented on the left side or a green disk on the right side). In the Irrelevant condition, the preceding task was the orientation-location task, which included 80 congruent trials (a vertical bar presented on the left side or a horizontal bar on the right side) and 80 incongruent trials (a horizontal bar presented on the left side or a vertical bar on the right side). The color-location task used as the test task was the same as that in the Relevant condition.

In both conditions, the preceding and test tasks were alternated in every trial. Half of the trials of the test task (40 congruent and 40 incongruent trials) were performed immediately after the congruent trial of the preceding task, and the other half were performed after the incongruent trial of the preceding task. In each trial, the stimulus remained on the monitor until the participants registered a response. Furthermore, each task was followed by an 800 ms interval during which a fixation-cross appeared on the center of the monitor. Then the next trial began. Participants were allowed to have a short break in the middle of the experiment.

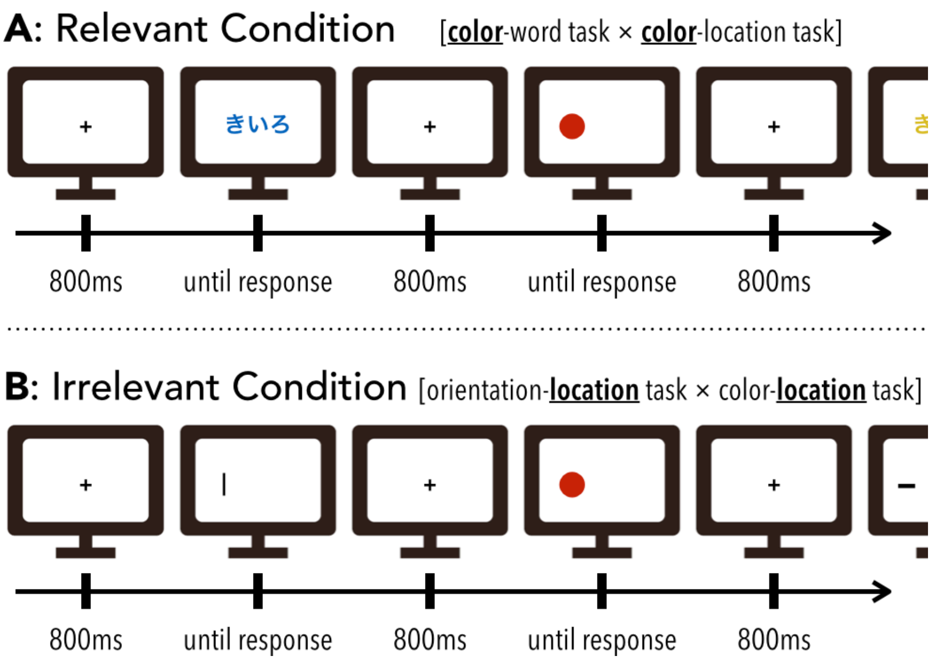

Figure 10 Design of Experiment 1. A: relevant condition. B: irrelevant condition.

2.1.2 Results

Trials in which the participants registered incorrect responses or in which RT was longer than the mean RT + 2.5 *SD* or shorter than the mean RT − 2.5 *SD* (no case) for a participant were excluded from the analyses. In addition, data was also discarded in cases in which the participants registered incorrect responses in the preceding trial.

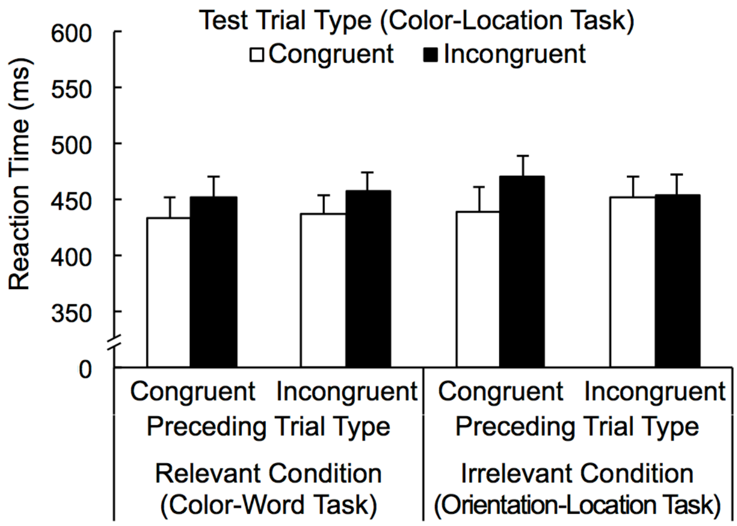

Figure 11 Result of Experiment 1. Error bar shows one standerd error of the mean (*SEM*).

Figure 11 shows the mean RT. A repeated measures analysis of variance (ANOVA) with conditions (Relevant and Irrelevant), trial type of the preceding task (congruent and incongruent), and trial type of the test task (congruent and incongruent) was conducted on the RT data of the test task. The results revealed a significant main effect of the trial type of the test task [F (1, 17) = 16.829, $p < .001$]; a significant interaction between the trial types of the preceding and test tasks [F (1, 17) = 5.612, $p < .05$]; and a significant three-way interaction of the condition, the trial type of the preceding task, and the trial type of the test task [F (1, 17) = 6.342, $p < .05$]. No other main effect or interaction was found to be significant. When the preceding task was the color-word task (in the Relevant condition), RT in Congruent-Congruent sequences (a congruent preceding trial followed by a congruent test trial) was shorter than that in Congruent-Incongruent sequences (a congruent preceding trial followed by an incongruent test trial) (433 vs. 452 ms, $p < .01$). Similarly, RT in Incongruent-Congruent sequences (an incongruent preceding trial followed by a congruent test trial) was shorter than that in Incongruent-Incongruent sequences (an incongruent preceding trial followed by an incongruent test trial) (436 vs. 457 ms, $p < .005$). In contrast, when the preceding task was the orientation-location task (in the Irrelevant condition), RT in Congruent-Congruent sequences was shorter than that in Congruent-Incongruent sequences (439 vs. 471 ms, $p < .001$), but there was no difference between RT in Incongruent-Congruent and Incongruent-Incongruent sequences (451 vs. 454 ms). Furthermore, RT in Congruent-Incongruent sequences was longer than that in Incongruent-Incongruent sequences ($p < .001$), but there was no difference between RT in Congruent-Congruent and Incongruent-Congruent sequences.

2.1.3 Discussion

Experiment 1 examined the modulation of cognitive control by the transient context at the processes of task-relevant and task-irrelevant information. In the Relevant condition, the stimuli of the two tasks had the same task-relevant attribute (color) and different task-irrelevant attributes (word and location). Thus, the performance of the test trial could be influenced by conducting the preceding trial only at the task-relevant process. The results showed that regardless of the congruency of the preceding task, RT of the test task was shorter in congruent trials than in incongruent trials. In short, transient modulation was not found in this situation, suggesting that the task-relevant process was not modulated by the transient context. In contrast, the Irrelevant condition examined the modulation of cognitive control by preceding trial types at the task-irrelevant process. In this condition, the stimuli of the two tasks had the same task-irrelevant attribute (location) and different task-relevant attributes (orientation and color). Thus, the performance of the test trial could be influenced by conducting the preceding trial only at the task-irrelevant process. The results revealed that the congruency effect was found when the preceding trial was congruent but not when it was incongruent, showing the effect of the transient context. Therefore, transient modulation in this situation suggests that the task-irrelevant process is modulated by the transient context. Thus, Experiment 1 revealed that transient modulation occurs at the task-irrelevant process. This finding supports the account of enhanced inhibition

(Stürmer et al., 2002; Wendt et al., 2006).

2.2 Experiment 2

Experiment 2 examined whether the sustained context affects the task-relevant and/or the task-irrelevant processes. For this purpose, a proportion of congruent/incongruent trials of the preceding tasks (color-word task in the Relevant condition and orientation-location task in the Irrelevant condition) was manipulated. In a congruent block, all trials of the preceding task were congruent, whereas in an incongruent block all trials of the preceding task were incongruent. As for the test task (color-location task in both the Relevant and Irrelevant conditions), half of the trials were congruent and the other half were incongruent in both blocks. Thus, as a whole, three-quarters of trials were congruent in the congruent block and three-quarters of trials were incongruent in the incongruent block. If there was any difference in congruency effect between the congruent and incongruent blocks, this modulation would be attributed to the effect of a sustained context (proportion of the congruent and incongruent trials in a block).

2.2.1 Method

2.2.1.1 Participants

Eighteen volunteers (10 women and 8 men, 19–29 years of age, M = 23.0 years) participated in the experiment. All volunteers reported having normal or corrected-to-normal vision and were not familiar with the purpose of the experiment. All participants performed the tasks under both the Relevant and Irrelevant conditions, with their order being counterbalanced. All participants provided written informed consent. They gave permission to use their data in the analysis.

2.2.1.2 Stimuli, Design, and Procedure

Apparatus and stimuli were the same as that in Experiment 1.

Two blocks (congruent and incongruent blocks) were used in both conditions. The congruent block included 80 preceding task trials (all congruent) and 80 test task trials (40 congruent and 40 incongruent), and the incongruent block included 80 preceding task trials (all incongruent) and 80 test task trials (40 congruent and 40 incongruent). In both conditions and blocks, the preceding and test tasks were run alternately in each trial. The trial sequence was randomized in a single block, and the block order was counterbalanced among participants.

2.2.2 Results

The mean RT was calculated in the same manner as that in Experiment 1. Figure 12 shows the results. A repeated measures analysis of variance (ANOVA) with conditions (Relevant and Irrelevant), the block type (congruent and incongruent), and the trial type of the test task (congruent and incongruent) was conducted on the RT data of the test task. The results reveal a significant main effect of the trial type of the test task [F (1, 17) = 17.119, $p < .001$]; a significant interaction between the block type and trial type of the test task [F (1, 17) = 5.612, $p < .05$]; and a significant three-way interaction of the condition, the block type, and the trial type of the test task [F (1, 17) = 6.342, $p < .05$]. No other main effect or interaction was found to be significant. When the preceding task was the color-word task (in the Relevant condition), RT in the congruent trials was shorter than that in the incongruent trials of the test task both in the congruent block (463 vs. 496 ms, $p < .001$) and the incongruent block (461 vs. 483 ms, $p < .05$). In contrast, when the preceding task was the orientation-location task (in the Irrelevant condition), RT in the congruent trials was shorter than that in the incongruent trials in the congruent block (438 vs. 487 ms, $p < .001$). However, RT in the congruent trials was longer than that in the incongruent trials in the incongruent block (487 vs. 462 ms, $p < .01$). In addition, RT in the congruent trials was shorter when the block type was congruent than when the block type was incongruent ($p < .001$), and RT in the incongruent trials was longer when the block type was congruent than when the block type was incongruent ($p < .001$).

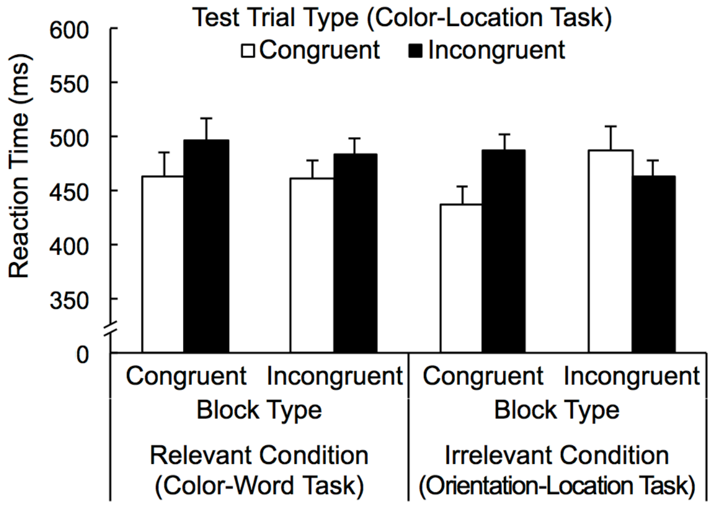

Figure 12 Result of Experiment 2. Error bars indicate one *SEM*.

In addition, the reverse congruency effect (RT on congruent trials - RT on incongruent trials) was compared between the first half and the second half in the incongruent block of the irrelevant condition. As a result, the reverse congruency effect was larger in trials of the second half than in trials of the first half (Figure 13), t (17) = -2.226, $p < .05$.

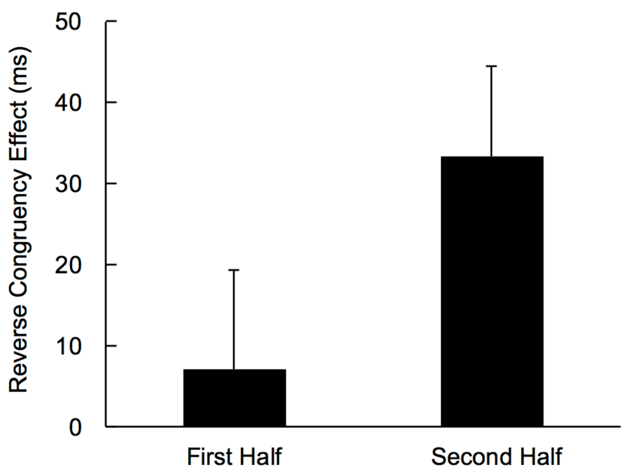

Figure 13 Reverse congruency effect (reaction time (RT) on congruent trials – RT on incongruent trials) in the first half and the second half of the incongruent block, the irrelevant condition of Experiment 2. Error bars indicate one *SEM*.

2.2.3 Discussion

Experiment 2 examined the modulation of cognitive control in the sustained context at the processes of task-relevant and task-irrelevant information. Results of the Relevant condition showed that regardless of the block type (congruent/incongruent), RT was consistently shorter in the congruent trials than in the incongruent trials of the test task. In short, sustained modulation was not found in the situation where the task-relevant information was commonly processed in the preceding and the test tasks. In contrast, the results of the Irrelevant condition showed that the congruency effect was found in the congruent block but not in the incongruent block, revealing the effect of the sustained context. That is, sustained modulation occurred at the process of task-irrelevant information, which agrees with the case of the transient modulation examined in Experiment 1. However, remarkable differences between the results of Experiment 1 and Experiment 2 should also be pointed out; no congruency effect was found in the Irrelevant condition of Experiment 1, whereas a reverse congruency effect was found in the Irrelevant condition of Experiment 2. This point will be further discussed in the next section.

2.3 Conclusion

The present study investigated whether transient and sustained contexts affect the task-relevant and/or the task-irrelevant processes. In Experiment 1, we examined the effect of the transient context. The results showed that transient modulation occurred only when the preceding task was an orientation-location task that had the same task-irrelevant stimulus information as the test task. This suggests that the task-irrelevant process is influenced by the transient context. In Experiment 2, we examined the effect of the sustained context. The results showed that sustained modulation occurred only when the preceding task was an orientation-location task, similar to that in case of the transient context (Experiment 1). This suggests that the task-irrelevant process is influenced by the sustained context too. In short, with regard to the first question raised in this study, "facilitation/inhibition" problem, the present results apparently support the inhibition account that predicts the modulation of the task-irrelevant process (Stürmer et al., 2002; Wendt et al., 2006).

In contradiction to our findings, some researchers have advocated the facilitation account (Egner & Hirsch, 2005; Notebaert & Verguts, 2008). For instance, Notebaert and Verguts (2008) suggested a facilitation-driven transient modulation in the similar task switching experiment to the present study. Their results showed a cross task modulation between the Simon task and the SNARC task: the Spatial Numerical Association of Response Codes task (Dehaene, Bossini, & Giraux, 1993), which have the same task-relevant information (color). The SNARC effect is an interference by the mental representation of numerical spatial sequence that is activated by the task-irrelevant numerical information, when making a spatial response based on the task-relevant information (e.g., color). Therefore this cross task modulation has been pointed out to be probably caused by not only the task-relevant process, but also the task-irrelevant process, because the task-irrelevant information in both tasks could be spatially processed (Funes et al., 2010). Furthermore, as regards the sustained modulation demonstrated as a reverse congruency effect in the present Experiment 2, the facilitation account is insufficient. This is because no matter how much the task-relevant process is facilitated, the congruency effect should not be reversed. As further discussed in the next paragraph, the reverse congruency effect should be explained by modulation of the task-irrelevant process.

Next, let us consider about our second question; comparison between the transient and the sustained modulation. According to the inhibition account (Stürmer et al., 2002; Wendt et al., 2006), response activation based on the task-irrelevant process is inhibited by experiencing the current conflict and expecting an approaching conflict. It should be noted that when this inhibition is achieved completely, task-irrelevant information is no longer effective and the congruency effect would disappear. Indeed, in Experiment 1, there was no difference between RTs in the Incongruent-Congruent and Incongruent-Incongruent sequences when the preceding and test tasks had the same task-irrelevant information (the Irrelevant condition). This result agrees with the idea of the inhibition account. Moreover, the fact that RT for the incongruent trials was influenced to be shorter, but RT for the congruent trials was not influenced, by being preceded by an incongruent trial, is consistent with this view. However, the effect of the sustained context cannot be explained by this account, because in Experiment 2, a reverse congruency effect was observed in the incongruent block when the preceding and test tasks had the same task-irrelevant information (the Irrelevant condition). This indicates that the participants found the congruent trials to be more difficult than the incongruent trials. If the response activation based on the task-irrelevant process is just inhibited, the congruency effect is not expected to be reversed; it would be erased at best. Here, the reverse congruency effect is key issue for considering the differences between the transient and sustained modulations (Iani, Rubichi, Gherri, & Nicoletti, 2009).

One possible explanation for this difference is that the way of utilizing task-irrelevant information would differ in these two situations. The transient context causes participants to ignore the task-irrelevant information, resulting in the absence of the congruency effect (Experiment 1). The sustained context, in contrast, causes the task-irrelevant information to be utilized in the opposite manner. That is, participants may create a reverse response biasing to the stimulus location in such a manner that the stimulus presented on the left side activates a response with the right hand and vice versa, resulting in the reverse congruency effect (Experiment 2). In the sustained situation, to learn the nature of current context for establishing a new response rule is undoubtedly an adaptive behavior, because responding with the hand opposite to the stimulus location is required in most trials in the sustained context.

To further examine this hypothesis, additional analysis was conducted by dividing the data in the incongruent block of the irrelevant condition of Experiment 2 into halves. This result would support the response biasing hypothesis by suggesting different degree of learning the context between the early and latter periods of experimental block. The above argument which assumes different use of the task-irrelevant information between transient and sustained contexts is in line with recent research that stresses the difference, rather than the similarity, between the transient and sustained modulations (Fernandez-Duque & Knight, 2008; Funes et al., 2010; Mayr & Awh, 2009).

In conclusion, the present study demonstrates similarities and possible differences between transient and sustained modulations of cognitive control. In both types of contextual modulations, the task-irrelevant process was shown to be influenced. In transient modulation, the task-irrelevant process was inhibited and no congruency effect was observed. In contrast, in sustained modulation, utilization of the task-irrelevant information changes depending on the current context, which results in a reverse congruency effect. Although it is unclear whether these findings could be generalized to various conflict tasks other than the spatial conflict task (color-location task) examined here, the current results suggest flexible and adaptive nature of the cognitive control. However, we should also note the limitation of this study with regard to stimulus manipulations. In the current experiments, stimulus attributes and task settings have some inconsistencies between conditions. Only the preceding task of the Relevant condition (a type of the Stroop task) entailed a stimulus and response conflict. Hence, this task may have been more difficult than the other tasks employed (a type of the Simon task), which only entailed a response conflict. Moreover, relevant information of employed tasks was either color or orientation, whereas irrelevant information was either word or location. This indicates that spatial code (stimulus location) was only included in the task-irrelevant information. Thus, we cannot rule out the possibility that the task-irrelevant process in the current experiments was contaminated by the specific influence of spatial coding. To evaluate the possible influence of these inconsistencies and strengthen the current findings, further studies employing various stimuli and tasks are needed.

Chapter 3
Conflict Monitoring vs. Contingency Learning

3.1 Experiment 3

In Experiment 3, it was examined the processing of the task-irrelevant information during the sustained modulation, which has not been extensively examined by previous studies. In Experiment 3, each participant performed the Simon task over two blocks of trials; one 80%-congruent and the other 80%-incongruent. The 80%-congruent block contained 80% congruent, 10% incongruent, and 10% no-go trials. The 80%-incongruent block contained 80% incongruent, 10% congruent, and 10% no-go trials. In addition to the RT on congruent and incongruent trials, FA rate in each FA type (same or opposite) on no-go trials was examined as an index of the response bias.

3.1.1 Method

3.1.1.1 Participants

Eighteen volunteers (10 women and 8 men; 21–32 years of age, M = 24.1 years) participated. All participants reported normal or corrected-to-normal vision. All participants provided written informed consent. They gave permission to use their data in the analysis.

3.1.1.2 Apparatus and Stimuli

Apparatus was the same as that in Experiment 1.

A disk (1° of visual angle) was displayed in one of three colors (red, green, and gray) on the left or right side (2° away from the center) of the monitor. The background color was consistently black.

3.1.1.3 Design and Procedure

Participants were asked to press the “C” key on a keyboard with the left index finger when the stimulus color was green, the “M” key with the right index finger when the stimulus color was red, and to refrain from pressing any key when the stimulus color was gray. This stimulus-response mapping was the same for all participants. The stimulus was presented until the response was offered or 1000 ms passed without a response. A response–stimulus interval (RSI) was 800 ms, during which a white fixation cross was presented at the center of the monitor.

Participants performed two separate blocks (80%-congruent and 80%-incongruent blocks), each consisting of 480 experimental trials. The 80%-congruent block had 384 congruent trials (a green disk was presented on the left side or a red disk on the right side), 48 incongruent trials (a green disk was presented on the right side or a red disk on the left side), and 48 no-go trials (a gray disk was presented either on the left or right side). The 80%-incongruent block had 48 congruent trials, 384 incongruent trials, and 48 no-go trials. The block order was counterbalanced and the trial order in each block was randomized among participants. Participants were permitted a short rest between blocks. They were not informed about the proportion of congruent/incongruent trials in a block. In fact, none of the participants noticed this manipulation until the debriefing after the experiment.

3.1.2 Results

3.1.2.1 Reaction Time on Congruent and Incongruent Trials

Trials which elicited an incorrect response or invoked longer or shorter RT than the mean RT ± 2.5 *SD* for each participant, were excluded from the analyses. In addition, data were also discarded when an incorrect response occurred on an immediately preceding trial. The RTs were analyzed by a two-way repeated measures analysis of variance (ANOVA) with the block type (80%-congruent and 80%-incongruent) and the current trial type (congruent and incongruent). Figure 14 illustrates the results. There was a significant interaction between two factors [F (1, 17) = 87.26, p < .001] and a significant main effect of the current trial type [F (1, 17) = 28.47, p < .001]. The main effect of the block type was not significant [F (1, 17) = 2.54, p = .12]. Post-hoc analyses (Cohen, 1988; Ryan, 1960) indicated that, when the block type was 80%-congruent, RT on the incongruent trials was longer than RT on the congruent trials (p < .001), and vice versa when the block type was 80%-incongruent (p < .05). In addition, RT on the congruent trials was shorter in the 80%-congruent than in the 80%-incongruent block (p < .001), and vice versa on the incongruent trials ($p < .001$). Therefore, we confirmed the sustained modulation of cognitive control, because the reverse congruency effect was clearly observed in the 80%-incongruent block.

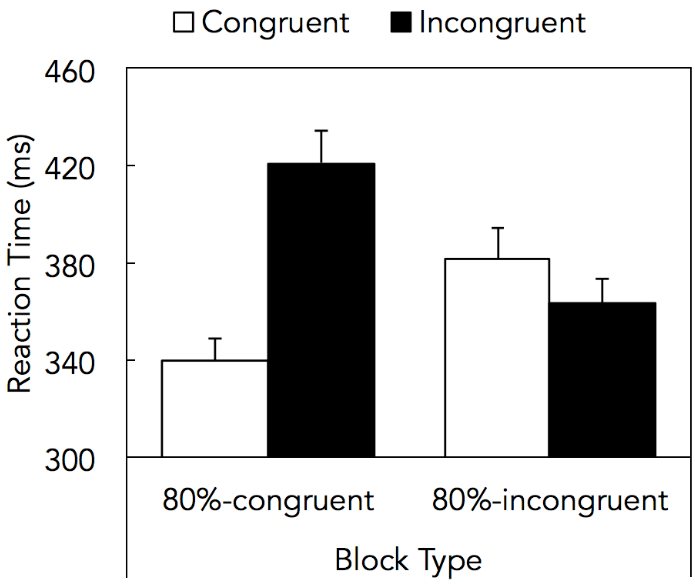

Figure 14 Mean reaction time in Experiment 3. Error bars indicate one *SEM*.

3.1.2.2 False Alarm on No-go Trials

The mean FA rates on no-go trials are depicted in Figure 15A. The FA rates were analyzed by a repeated measures ANOVA with the block type (80%-congruent and 80%-incongruent) and the FA type (same and opposite). The "same FA" refers to an FA response made by the hand on the same side as the stimulus location and the "opposite FA" is that made by the hand opposite to the stimulus location. There was a significant main effect of the block type [F (1, 17) = 8.32, $p < .05$], a significant main effect of the FA type [F (1, 17) = 7.01, $p < .05$], and a significant interaction between two factors [F (1, 17) = 40.22, $p < .001$]. Post-hoc analyses (Cohen, 1988; Ryan, 1960) indicated that, when the block type was 80%-congruent, the same FA was more frequent than the opposite FA ($p < .001$). In contrast, when the block type was 80%-incongruent, the opposite FA was more frequent than the same FA ($p < .001$). In addition, the same FA rate was higher in the 80%-congruent than 80%-incongruent block ($p < .001$). Conversely, the opposite FA rate was lower in the 80%-congruent than 80%-incongruent block ($p < .001$).

Furthermore, data of only the complete change no-go trials were analyzed. These are no-go trials whose stimulus location is different from that of the preceding trial. Results are shown in Figure 15B, and were analyzed by the same ANOVA as before. There was a significant interaction between two factors [$F(1, 17) = 33.782$, $p < .001$]. The main effect of the block type and the main effect of the FA type were not significant [$F(1, 17) = 0.53$, $p = .48$; $F(1, 17) = 0.44$, $p < .52$]. Post-hoc analyses (Cohen, 1988; Ryan, 1960) indicated that, when the block type was 80%-congruent, the same FA was more frequent than the opposite FA ($p < .001$). In contrast, when the block type was 80%-incongruent, the opposite FA was more frequent than the same FA ($p < .001$). In addition, the same FA rate was higher in the 80%-congruent than 80%-incongruent block ($p < .001$). Conversely, the opposite FA rate was lower in the 80%-congruent than 80%-incongruent block ($p < .001$).

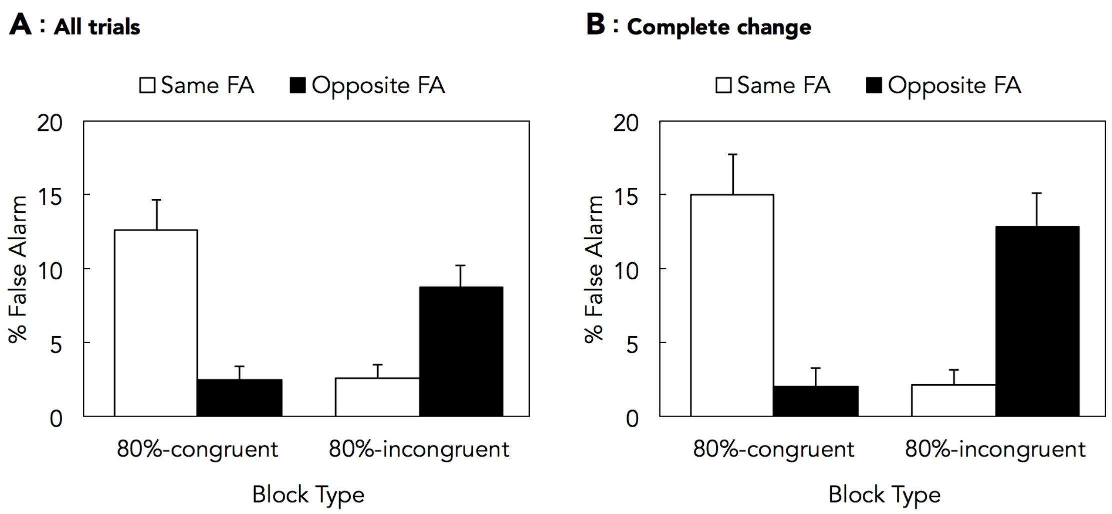

Figure 15 FA rates on no-go trials in Experiment 3; error bars indicate standard errors of the mean. A: FA rates on all no-go trials. B: FA rates on the complete change no-go trials.

3.1.2.3 Correlation between the response biasing and the reverse congruency effect

If the reverse congruency effect was caused by the response biasing, it is assumed that the individual having greater response biasing would yield greater reverse congruency effect. To test this assumption, the degree of contralateral biasing (opposite FA rate minus same FA rate) and the degree of reverse congruency effect (RT on congruent trials minus RT on incongruent trials) in 80%-incongruent block was obtained for each participant, and the correlation of these values was calculated. As shown in Figure 16, this correlation was significant ($r = .56$, $p < .05$).

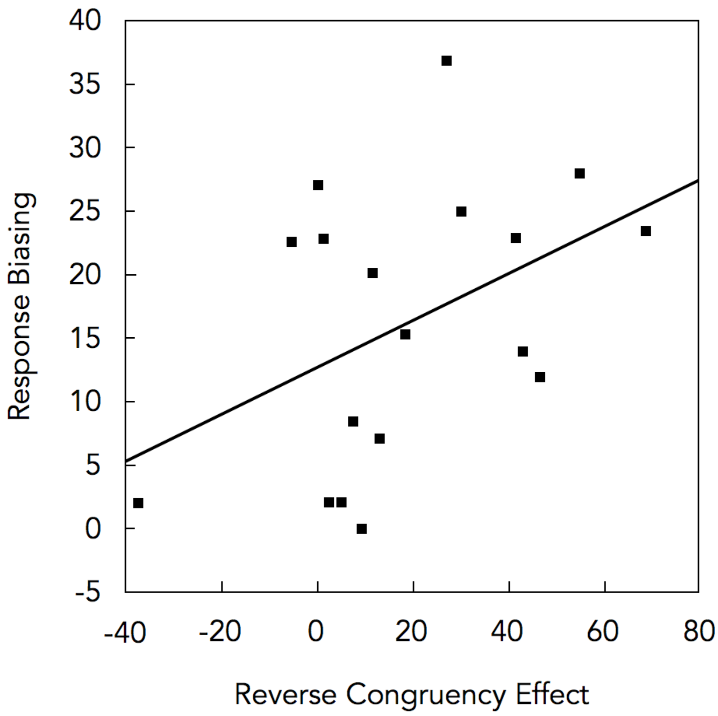

Figure 16 Correlation between the response biasing and the reverse congruency effect in the 80%-incongruent block of Experiment 3.

3.1.3 Discussion

In Experiment 3, effect of the sustained modulation of cognitive control was clearly observed; RT was shorter on the congruent than incongruent trials in the 80%-congruent block, whereas this trend was reversed in the 80%-incongruent block. And, more importantly, the frequency of FA response on the same side as the stimulus location was higher than that on the opposite side in the 80%-congruent block, and vice versa in the 80%-incongruent block. This result suggests a generation of the utilization bias of task-irrelevant information in the 80%-incongruent block (Ridderinkhof, 2002; Schmidt, 2013; Schmidt & Besner, 2008). This tendency of reversing FA rates was found regardless of whether the analysis was done for data of all no-go trials or for data of only the complete change no-go trials, suggesting that the effect of the repetition priming was small. In addition, there was a significant positive correlation between the response biasing and the reverse congruency effect. These results fit with the response biasing account based on the contingency learning of association between the task-irrelevant information and the response mapping (Schmidt, 2013; Schmidt & Besner, 2008).

Before concluding that the response bias is a cause of the sustained modulation, possibility of its being generated by the trial-by-trial adaptation, not by the sustained conflict context, should be eliminated. Otherwise, the effect of block type observed in this experiment might be confounded with the effect of transient (trial-by-trial) modulation, since not only the proportion of congruent and incongruent trials but also the probable relationship of congruency between successive two trials would have been varied by the block type. Consequently, in Experiment 4, we examine the effect of trial-by-trial modulation of cognitive control on the same response bias as that shown in Experiment 3.

3.2 Experiment 4

In Experiment 4, to examine the effect of only the transient modulation (i.e., to exclude the effect of the sustained modulation), the same proportion of congruent and incongruent trials were presented: 45% congruent, 45% incongruent, and 10% no-go trials. FA rates on no-go trials were examined separately for the preceding trial types, congruent and incongruent. If the response bias observed in Experiment 3 could be generated by the trial-by-trial, not by the sustained modulation, similar bias should be observed even when the congruent and incongruent trials were presented with equal probability. Furthermore, according to the dual control account (Braver, 2012; De Pisapia & Braver, 2006; Ridderinkhof, 2002), inhibition of the task-irrelevant processing would be enhanced by the transient conflict context. As such, if there was a transient enhancement of inhibition, the overall FA rate on no-go trials should be lower when preceded by an incongruent trial than by a congruent trial.

3.2.1 Method

3.2.1.1 Participants

Eighteen volunteers (10 women and 8 men; 21–32 years of age, $M = 24.3$ years) participated. All participants reported normal or corrected-to-normal vision. All participants provided written informed consent. They gave permission to use their data in the analysis.

3.2.1.2 Apparatus, Stimuli, Design, and Procedure

Apparatus, stimuli, experimental design, and procedure were the same as in Experiment 3 with the following exception. Participants performed 480 experimental trials in one block: 216 congruent, 216 incongruent, and 48 no-go trials. The trial order was pseudo-randomized for each participant to present an equal number of no-go trials after the congruent and incongruent trials (i.e., 24 trials each).

3.2.2 Results

3.2.2.1 Reaction Time on Congruent and Incongruent Trials

The RTs were calculated in the same way as in Experiment 3 and analyzed by a repeated measures ANOVA with the preceding trial type (congruent and incongruent) and the current trial type (congruent and incongruent). Figure 17 shows the results. There was a significant main effect of the current trial type [$F(1, 17) = 56.81$, $p < .001$] and a significant interaction between two factors [$F(1, 17) = 48.09$, $p < .001$]. The main effect of the preceding trial type was not significant [$F(1, 17) = 2.26$, $p = .15$]. Post-hoc analyses (Cohen, 1988; Ryan, 1960) showed that, when the preceding trial type was congruent, RT on the incongruent current trials was longer than RT on the congruent current trials ($p < .001$). In contrast, when the preceding trial type was incongruent, RTs on the congruent and incongruent current trials did not differ significantly ($p = .54$). In addition, RT on the congruent current trials was shorter when the preceding trial type was congruent than incongruent ($p < .001$), and vice versa on the incongruent current trials ($p < .001$). Therefore, we confirmed the transient modulation of cognitive control in this experiment, in that the congruency effect was observed only when the preceding trial type was congruent.

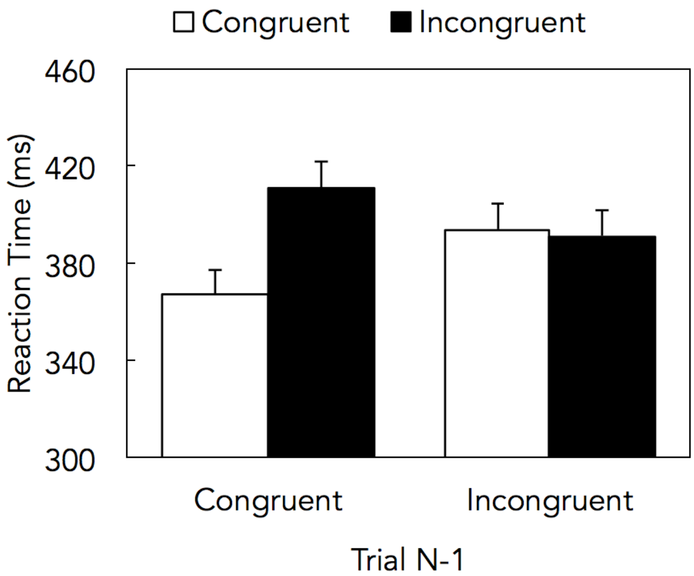

Figure 17 Mean reaction times in Experiment 4. Error bars indicate one *SEM*.

3.2.2.2 False Alarm on No-go Trials

The mean FA rates on the no-go trials are shown in Figure 18A. The FA rates were analyzed by a repeated measures ANOVA with the preceding trial type (congruent and incongruent) and the FA type (same and opposite). There was a significant main effect of the preceding trial type [F (1, 17) = 4.89, $p < .05$], a significant main effect of the FA type [F (1, 17) = 6.23, $p < .05$], and a significant interaction between two factors [F (1, 17) = 14.143, $p < .005$]. Post-hoc analyses (Cohen, 1988; Ryan, 1960) showed that, when the preceding trial type was congruent, the same FA was more frequent than the opposite FA ($p < .001$). In contrast, when the preceding trial type was incongruent, there was no difference between the rates of two FA types ($p = .64$). In addition, the same FA rate was higher after congruent than incongruent trials ($p < .001$), whereas the opposite FA rate did not differ significantly between the preceding trial types (p = .30).

Next, as in Experiment 1, mean FA rates on only the complete change no-go trials were calculated (Figure 18B), and analyzed by a repeated measures ANOVA with the preceding trial type and the FA type. There was a marginally significant main effect of the preceding trial type [F (1, 17) = 3.45, p = .08], a significant main effect of the FA type [F (1, 17) = 15.00, p < .005], and a significant interaction between two factors [F (1, 17) = 24.359, p < .001]. Post-hoc analyses (Cohen, 1988; Ryan, 1960) showed that, when the preceding trial type was congruent, the same FA was more frequent than the opposite FA (p < .001). In contrast, when the preceding trial type was incongruent, there was no difference between the rates of two FA types (p = .34). In addition, the same FA rate was higher after congruent than incongruent trials (p < .001), and the opposite FA rate was lower after congruent than incongruent trials (p = .05).

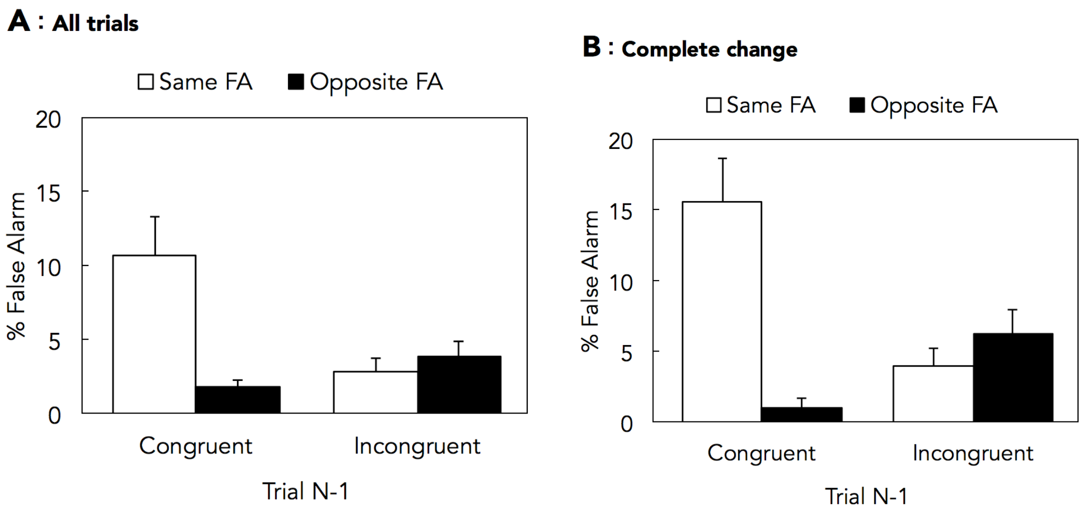

Figure 18 FA rates on no-go trials in Experiment 4; error bars indicate standard errors of the mean. A: FA rates on all no-go trials. B: FA rates on the complete change no-go trials.

3.2.2.3 Correlation between the response biasing and the reverse congruency effect

Though significant reverse congruency effect was not found when the preceding trial type was incongruent, the same correlational analysis as that in the 80%-incongruent block of Experiment 1 was conducted between the degree of contralateral biasing and the degree of the reverse congruency effect on trials preceded by an incongruent trial. As shown in Figure 19, this correlation was not significant (r = -.07, p = .78).

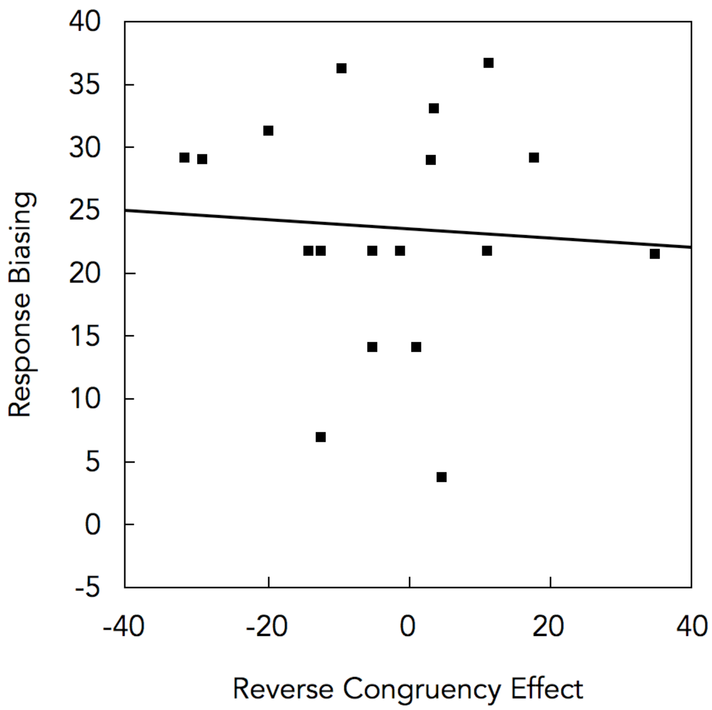

Figure 19 Correlation between the response biasing and the reverse congruency effect when the preceding trial type was incongruent in Experiment 4.

3.2.3 Discussion

The present results showed that RT on congruent trials was shorter than RT on incongruent trials when the preceding trial type was congruent whereas no congruency effect was observed when the preceding trial type was incongruent; thus, the transient modulation of cognitive control was shown. More importantly, the FA analysis demonstrated that, unlike Experiment 1, the preceding trial type did not reverse the dominant FA type. When the preceding trial type was congruent, FAs were made more frequently by the hand on the same side as the stimulus location than by the hand on the opposite side, which was the same result as in the 80%-congruent block of Experiment 3. Conversely, when the preceding trial type was incongruent, the same and opposite FA rates did not differ significantly, although the former was slightly lower than the latter. Furthermore, the overall FA rate was significantly lower after the incongruent trial than after the congruent trial, supporting the dual control account (Braver, 2012; De Pisapia & Braver, 2006; Ridderinkhof, 2002) that assumes response inhibition for the task-irrelevant information is enhanced by the transient context. These results are decisively different from those in the 80%-incongruent block of Experiment 1, in which the opposite FA rate was significantly higher than the same FA rate, and fit with inhibition account (Stürmer et al., 2002) and the micro-adjustment/reactive-control supposed by the dual control account (Braver, 2012; De Pisapia & Braver, 2006; Ridderinkhof, 2002).

Collectively, these results suggest that location information of the no-go stimulus would automatically activate the same side response to induce the same FA when it was immediately preceded by the congruent trial, whereas such an automatic activation was inhibited after the incongruent trial. Consequently, the present results indicate that the response bias observed in Experiment 3 was primarily due to the sustained, rather than the transient, modulation of cognitive control. The transient conflict context would trigger inhibition of the task-irrelevant processing, but wouldn't render the task-irrelevant information actively usable to lead to more opposite FAs and generate the reverse congruency effect as in the case of the sustained conflict context.

3.3 Conclusion

The present study investigated the difference in processing of the task-irrelevant information of the Simon task between sustained and transient contexts by analyzing FA responses on no-go trials. Experiment 3 demonstrated that the rate of FA response for the same side as the stimulus location was higher than that for the opposite side in the 80%-congruent block, and vice versa in the 80%-incongruent block, suggesting that response bias for the side opposite to the stimulus location was generated by experiencing a number of incongruent trials. However, such a response bias was not found in Experiment 4, which examined the trial-by-trial context. When the transient context was congruent (no-go trial was immediately preceded by a congruent trial), the same FA rate was higher than the opposite FA rate. However, when the transient context was incongruent, the same and opposite FA rates did not differ, contrasting with the sustained incongruent context in which the opposite FA rate exceeded the same FA rate (80%-incongruent block of Experiment 3).

Together, the present results show that response bias was depended on the overall proportion of congruent and incongruent trials. In other words, this bias may be a causal factor of the reverse congruency effect by the sustained modulation of cognitive control observed in Experiment 3. To support this view, a significant correlation was found between the degree of contralateral biasing and the degree of reverse congruency effect in the 80%-incongruent block. These results are consistent with the utilization bias account based on the contingency learning (Schmidt, 2013; Schmidt & Besner, 2008). Such a contingency learning seems to depend on property of the overall context formed by a number of prior trials rather than the immediate influence from the preceding trial, since the effect of the repetition priming was found to be small. In addition, in Experiment 3, no instruction about the proportion of congruent and incongruent trials was provided to the participants. In fact, subjective reports obtained following the experiment revealed that all participants were unaware of the variation in the proportion of congruent/incongruent trials between blocks, suggesting that the response bias was implicitly and automatically generated.

In Experiment 4, FA rate on no-go trials was lower after the incongruent trial than after the congruent trial. This result is consistent with the inhibition account (Stürmer et al., 2002) or the micro/reactive control account (Braver, 2012; De Pisapia & Braver, 2006; Ridderinkhof, 2002), which assumes that the demand for control generated by experiencing conflict in the preceding trial (i.e., short-term conflict context) inhibits response activation by the task-irrelevant information (i.e., stimulus location in the Simon task). Lower FA rate observed on trials immediately after an incongruent trial can be explained by such a hypothesized inhibition of the response activation at the onset of the no-go stimuli. Provided that the transient modulation of cognitive control is generated primarily through the mechanism of response inhibition, the present findings are consistently explained by the inhibition account.

As mentioned in the introduction, the relationship between the sustained and transient modulations remains controversial. The conflict-monitoring theory proposes that an accumulation of the transient modulation results in the sustained modulation of cognitive control (Botvinick et al., 2001; 2004), whereas other researchers have proposed that these modulations are controlled by different mechanisms such as reactive and proactive control (for the transient and sustained modulations, respectively) (Braver, 2012; De Pisapia & Braver, 2006; Funes et al., 2010). In line with the latter argument, Experiments 3 and 4 showed different patterns of response bias in FA, indicating that the sustained modulation is more than a simple accumulation of the transient modulation of cognitive control.

In summery, the present study suggests the dual modulation mechanism of cognitive control in the Simon task. In the transient trial-by-trial sequence, the task-irrelevant information would be inhibited, as expected by the conflict monitoring theory (Botvinick et al., 2001; 2004), the inhibition account (Stürmer et al., 2002), and the reactive control (Braver, 2012; De Pisapia & Braver, 2006). As for the sustained conflict context, however, the present results would come to a different conclusion from these accounts. We supports the contingency learning (Schmidt, 2013; Schmidt & Besner, 2008). The task-irrelevant information would be used in the reversed manner based on the contingency learning of association between the stimulus location and the response mapping. These suggest that the modulation of cognitive control is not achieved by the single mechanism. Rather, multiple mechanisms, including the active response bias demonstrated in the present study, should be assumed to work together to enable the adaptive behavior in conflict situations.

Chapter 4
Voluntary Control Modulation vs. Involuntary Optimization

4.1 Experiment 5

The aim of the present study is to reveal the role of awareness in the block-wise and trial-by-trial modulations. For this purpose, we employed the subliminal response conflict task (Kunde, 2003), and compered the congruency effects in between the neutral block (including 50% incongruent and 50% congruent trials) and the incongruent block (including 90% incongruent and 10% congruent trials). In addition, data were analyzed separately for trials immediately followed the congruent trial and trials immediately followed the incongruent trial in each block to examine the effect of the trial-by-trial modulation. Furthermore, we examined the state of meta-cognition in unconscious conflict situation by asking participants' self-evaluation of their performance in each block. It was conducted for looking at the possibility that sense of "difficulty" generated by the sustained conflict context may guide the modulation of cognitive control, even though participants cannot identify the primes (Desender & Van den Bussche, 2012; Kinoshita et al., 2008).

4.1.1 Method

4.1.1.1 Participants

Twenty volunteers (10 females and 10 males, 19–28 years of age, M = 22.0) participated. All reported having normal or corrected-to-normal vision. All participants provided written informed consent. They gave permission to use their data in the analysis.

4.1.1.2 Apparatus and Stimuli

The stimuli were displayed on a CRT monitor (GDM-F520, Sony, 100 Hz) controlled by a computer (MB324J/A, Apple) and Psychophysics Toolbox (Brainard, 1997).

In the masked priming task, left-pointing and right-pointing arrow-like figures were used as the prime and the target. The prime was 0.7° × 1° and the target was 1.7° × 2.4° of visual angle in size. The prime fitted exactly into the space in the middle of the target. The mask used in the prime discrimination task (see below) was depicted as an overlapped figure of a left-pointing and a right-pointing targets (Figure 20).

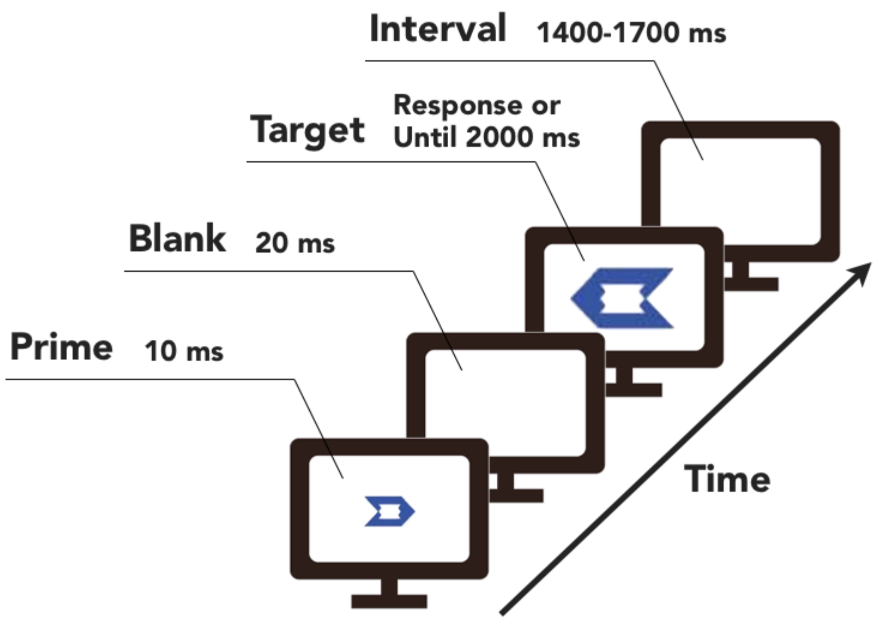

Figure 20 Design of Experiment 5.

4.1.1.3 Procedure

The prime was presented for 10 msec after inter-trial-interval (ITI), and was followed by a blank interval of 20 msec. Then the target was presented for 120 msec. Participants were asked to press, as quickly and accurately as possible, the "F" key on a keyboard with the left index finger for the left-pointing target, and the "J" key with the right index finger for the right-pointing target. The next trial was started after a response was made or 2000 msec passed without a response. The length of ITI was varied randomly within a range of 1400–1700 msec.

Participants performed two separate blocks (neutral and incongruent blocks), each consisted of 320 experimental trials. The neutral block had 160 congruent trials (the left-pointing target following the left-pointing prime or the right-pointing target following the right-pointing prime) and 160 incongruent trials (the left-pointing target following the right-pointing prime or the right-pointing target following the left-pointing prime). The incongruent block had 32 congruent trials and 288 incongruent trials. Participants were not given any information about the proportion of congruent/incongruent trials in a block. The block order was fixed in all participants: The neutral block was performed first. It was because possible biased effect of the incongruent block should not be carried over into the neutral block. The trial order in each block was randomized among participants. After performing each block, participants underwent an interview in which self-evaluation of their performance was asked by using two questions: “How fast did you respond?” and “How accurately did you respond?”, both on a 5-point scale (1: not well at all, 5: very well).

After finishing both blocks, participants were asked whether they noticed any difference between two blocks. Next, the prime discrimination task was conducted. At this time, before beginning the prime discrimination task, participants were informed that the prime was briefly presented before the target in the experiments they have just performed. Then, in the prime discrimination task, the mask, instead of the target, was presented following the prime, and participants were asked to answer the pointing direction of the prime (left or right, on two alternative forced choice). Forty trials (20 left and 20 right) were performed by each participant.

4.1.2 Results

4.1.2.1 Prime Discrimination Task

Mean correct response rate in the prime discrimination task was 51.8%, which was not significantly different from the chance level (50%) [t (19) = 1.02, p = .32].

4.1.2.2 Reaction Time in the Masked Priming Task

Mean reaction times (RTs) in the masked priming task (Figure 21) were analyzed by a three-way repeated measures analysis of variance (ANOVA) with the block type (neutral and incongruent), the preceding trial type (congruent and incongruent), and the current trial type (congruent and incongruent). There were a significant main effect of the current trial type [F (1, 19) = 189.06, p < .001]; and a significant interaction between the block type and the current trial type [F (1, 19) = 4.88, p < .05]. Any other main effects or interactions were not significant. Post-hoc analysis indicated that RT on the incongruent current trial was longer than RT on the congruent current trial in each block ($p < .001$) in the neutral block ($p < .001$) in the incongruent block. In addition, RT on the incongruent current trial was significantly shorter in the incongruent block than in the neutral block ($p < .05$), whereas RT on the congruent current trial was not different between blocks ($p = .65$).

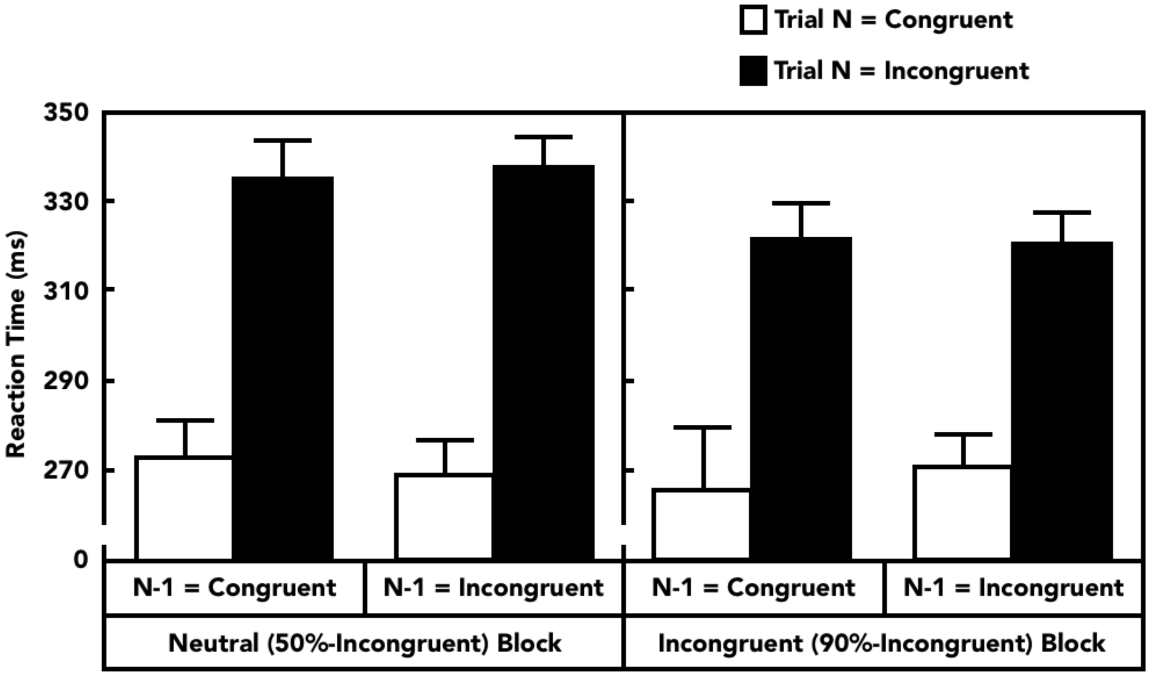

Figure 21 Mean reaction times in Experiment 5. Error bars indicate one SEM.

4.1.2.3 Error Rate in the Masked Priming Task

Mean error rate (ER) in the masked priming task (Figure 22) were analyzed by a three-way repeated measures analysis of variance (ANOVA) with the block type (neutral and incongruent), the preceding trial type (congruent and incongruent), and the current trial type (congruent and incongruent). As a result, a three-way interaction was significant [$F(1, 19) = 4.80$, $p < .05$]. Post-hoc analyses indicated that, ER on incongruent trial in neutral block was lower when the preceding trials was congruent than incongruent ($p < .001$). ER on incongruent trial when the preceding trial was congruent was higher in incongruent block than neutral blocks ($p < .001$). ER was higher on congruent than incongruent trials in any time, in neutral block when the preceding trial was congruent ($p < .001$); in neutral block when the preceding trial was incongruent (p

< .001); in incongruent block when the preceding trial was congruent (p < .005); in incongruent block when the preceding trial was incongruent (p < .005).

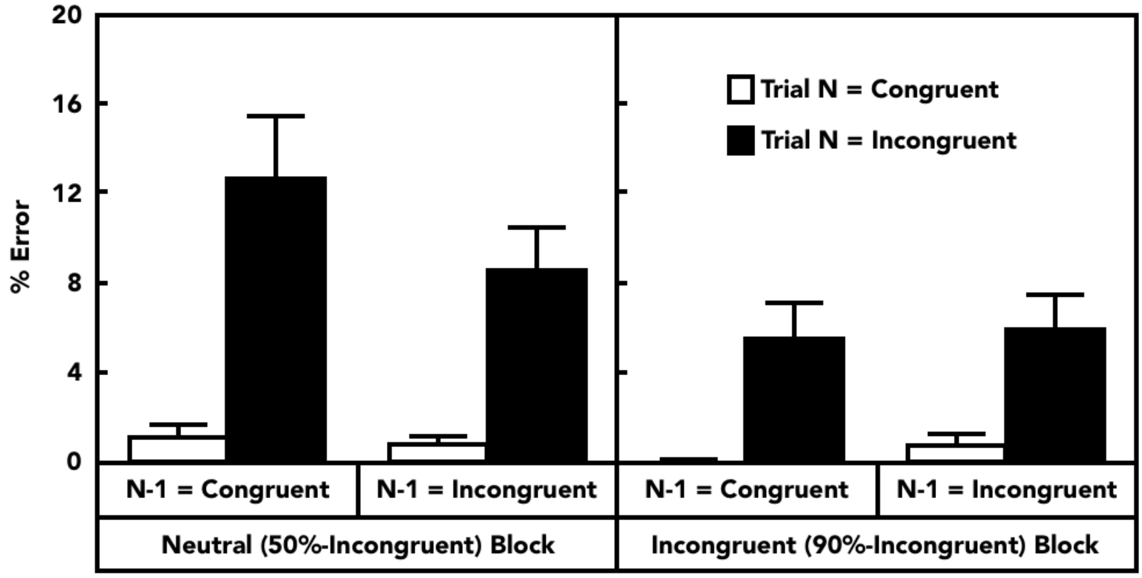

Figure 22 Mean error rates in Experiment 5. Error bars indicate one SEM.

4.1.2.4 Interviews

Results of the interviews about task performance (Figure 23), which were conducted after each block, were analyzed by two-way repeated measures ANOVA with the block type (neutral and incongruent) and the matter in question (speed and accuracy). There were significant main effects of the block type [F (1, 19) = 4.48, p < .05] and of the matter [F (1, 19) = 11.28, p < .005], but interaction of two factors was not significant [F (1, 19) = 0.25, p = .63].

As for the results of the final interview, none of participants pointed out the difference between blocks.

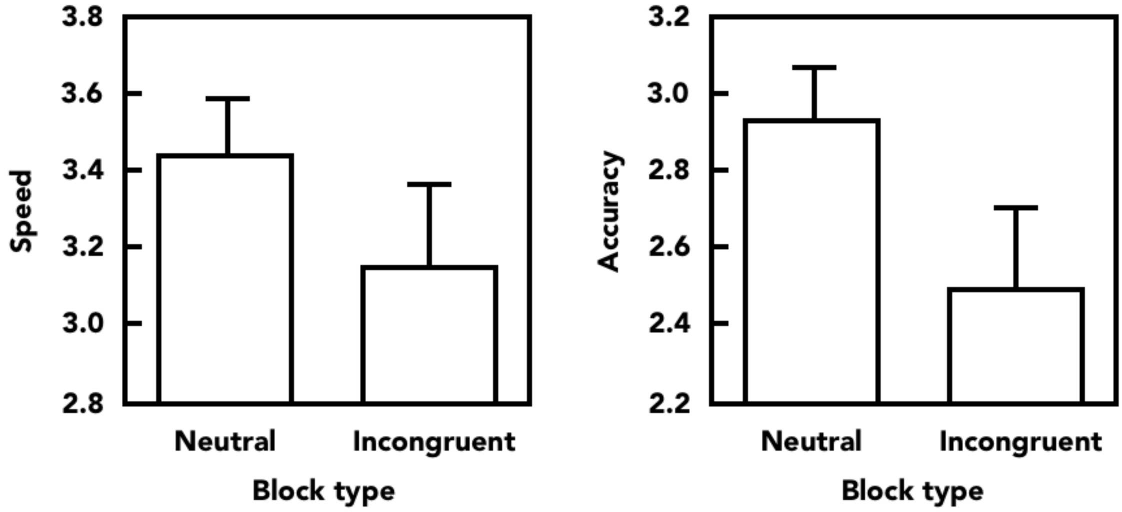

Figure 23 Mean rates of post experimental self-estimation about own performance (speed and accuracy) on 5-point scale in Experiment 5. Error bars indicate one SEM.

4.1.3 Discussion

In the present study, we examined the role of consciousness for the trial-by-trial and the block-wise adaptations of the cognitive control. As the results, RT data showed no trial-by-trial adaptation in both the neutral and the incongruent blocks, suggesting that awareness of the task-irrelevant information is necessary for the cognitive control to generate trial-by-trial modulation. Contrastingly, the block-wise adaptation was observed because RT on the incongruent trials was shorter in the incongruent block than in the neutral block. In addition, participants' meta-cognition of their task performance was influenced by the block type; better self-evaluation both for speed and for accuracy in the neutral block than in the incongruent block. Nevertheless, no participants could point out the difference between blocks at the end of the experiments, ensuring that the effects of block-wise adaptation on the task performance and the meta-cognition was derived unconsciously.

On the other hand, ER data showed that the enhancement in accuracy was observed not only in the block-wise context but also in the trial-by-trial context. As previously noted, Francken et al. demonstrated the trial-by-trial effect on only the accuracy measure (Francken et al., 2011). Furthermore, result of the accuracy reported by Kunde (2003) seems to show difference between conditions with congruent and incongruent preceding trial; but only by the visual inspection of the graph, since a statistical analysis of the data was not provided. Taken together, these results suggest that the trial-by-trial effect is limited to the cautiousness-shifting and does not improve the response quickness. Other results of the masked priming studies are consistent with this account; that is, the trial-by-trial effect on responder's cautiousness in the masked Go/No-Go task (van Gaal, Ridderinkhof, Fahrenfort, Scholte, & Lamme, 2008) and in the stop-signal task (van Gaal, Ridderinkhof, van den Wildenberg, & Lamme, 2009). These tasks do not require the response selection, thus the cautiousness-shifting is sufficient to improve performance.

Finally, the present results offered some suggestion about the meta-cognitive state. Kinoshita et al. argued that unconscious cognitive control may be triggered by the sense of difficulty, whereas awareness of conflict is not necessary (Kinoshita et al., 2008). Consistent with this argument, results of the meta-cognition interview revealed that both speed and accuracy were evaluated worse in the incongruent block than in the neutral block. This suggests that the block-wise control modulation may be triggered by a subtle conscious state. However, since the trial-by-trial conscious state was not investigated in the present study, relationship between the trial-by-trial cautiousness-shifting and the role of sense of difficulty is left unclear, which should be investigated in the future research.

4.2 Conclusion

The present study investigated the role of awareness in the trial-by-trial and the block-wise adaptation to the response conflict. As the results, there were a partial trial-by-trial adaptation (in accuracy only) and a complete block-wise adaptation (both in speed and accuracy) in the masked priming task. Therefore we concluded that awareness of response conflict is necessary for the trial-by-trial adaptation, but not for the block-wise adaptation. It could be summed that the sustained conflict context boosts conflict resolution, but the transient conflict context does not necessarily. If a response conflict was experienced unconsciously in the preceding trial, the process of conflict resolution would not be fully facilitated, triggering only the cautiousness-shifting.

Chapter 5 General Discussion

5.1 Summary and Significance of the Present Study

Experiments 1 and 2 in Chapter 2 was conducted with two aims: The first was to reveal which process, the task-relevant one or the task-irrelevant one, is changed by the transient and sustained contexts, and the second was to reveal the difference, if any, between the effects of these contexts. Results of two experiments suggested that, though both the transient and the sustained modulations occurred at the task-irrelevant process, these modulations would be different in nature; the transient modulation would be caused by just an inhibition of utilizing the task-irrelevant information, while the sustained modulation would be showing a newly started utilization of the task-irrelevant information as a result of participant's re-adaptation to the context.

Experiments 3 and 4 in Chapter 3 present new evidence supporting the above claim, by comparing false alarm (FA) responses on no-go trials of the Simon task between the sustained and transient contexts. In Experiment 3, the sustained context was manipulated so that a block included a larger number of incongruent trials. Results showed that participants made more FA responses by the hand opposite to the stimulus location. This suggests a generation of response bias in which the task-irrelevant location information is utilized in a reversed manner (i.e., to respond with the right hand to a stimulus presented on the left side and vice versa). Next, Experiment 4 examined the effect of the transient context and found that overall FA rate was lower when a no-go trial was preceded by an incongruent trial than by a congruent trial, whereas such response bias as that shown in Experiment 3 was not demonstrated. This suggests that the transient conflict context enhances inhibition of the task-irrelevant process but does not make the task-irrelevant information actively usable. Based on these results, two types of cognitive control modulations as adaptive behaviors were propounded: response biasing based on utilization of the task-irrelevant information under the sustained conflict context, and transient enhancement of inhibition of the task-irrelevant process based on the online conflict monitoring.

Finally, Experiment 5 in Chapter 4 examined the role of awareness in the transient and the sustained modulations. In the previous studies (Kunde, 2003), transient modulation was shown to be absent when the task-irrelevant information was presented subliminally. On the contrary, as noted in the conclusion of Chapter 3, it is often pointed out that the sustained modulation is due to the contingency learning, which has nothing to do with task set. According to this idea, though such learning requires co-activation of the task-irrelevant information and the correct response representation, it doesn't necessarily require an awareness of the conflict. As the result of Experiment 5, no effect of the preceding trial type (i.e., the transient context) was found. On the other hand, as for the sustained context, RT on the incongruent trials was shorter in the 90%-incongruent block than in the 50%-incongruent block. These results indicate that awareness of the response conflict is necessary for the transient modulation, but not for the sustained modulation. In addition, results of the 90%-incongruent block showed that the transient modulation was absent, while the sustained modulation was clearly observed. This suggests that the sustained modulation is not a simple accumulation of the transient modulation. In sum, to explain the unconscious sustained modulation demonstrated here, we need another mechanism than the conflict monitoring; and the best candidate would be contingency learning.

The summaries of these findings are shown in Table 2.

Table 2 Comparing the propaties in previous hypothetical models and evidences in the present study. The findings of transient modulation matched the inhibition account of the conflict monitoring theory (red indications), and the findings of sustained modulation matched the contingency learning (blue indications).

	Where?	What?	How?
Hypothetical Models in Previous Studies			
Conflict Monitoring			
Facilitation Account	Task-relevant Route	Route Amplification	Voluntary
Inhibition Account	Task-irrelevant Route	Route Suppression	Voluntary
Contingency Learning	Task-irrelevant Route	Creating a New Route	Involuntary
Feature Binding	Both	Using an Event File	Involuntary
Findings of the Present Study			
Transient Modulation	Task-irrelevant Route (Exp.1)	Route Suppression (Exp.4)	Voluntary (Exp.5)
Sustained Modulation	Task-irrelevant Route (Exp.2)	Creating a New Route (Exp.3)	Involuntary (Exp.5)

5.2 Hypothetical Model

5.2.1 Dual Modulation Model: Conflict Monitoring and Contingency Learning

It is now possible to construct a new model of our cognitive conflict management by integrating the empirical findings from the five experiments presented above. The schematic illustration of this model is shown in Figure 24. This model contains two modulation modules: the module of modulation of information gating based on the conflict monitoring and the module of modulation of the strength of S-R linkage based on contingency learning. Essential points of the model are explained as follows.

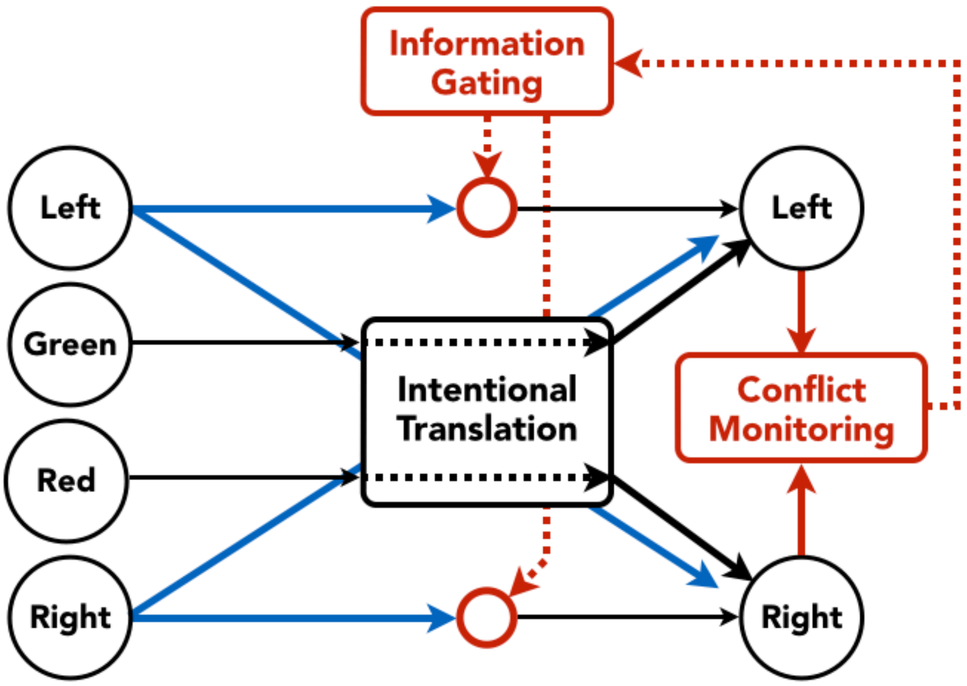

Figure 24 Dual modulation model of cognitive control in the Simon task. Red indications show transient modulation mechanism, and blue indications show sustained modulation mechanism.

5.2.1.1 Transient Modulation Based on Conflict Monitoring

Results of Experiments 2 and 4 suggest that experience of conflict in the preceding trial boosts inhibition of the location-based response activation. In this model, the transient modulation is explained as a feedback-loop of the conflict detection and the top-down control demand in the same manner as the conflict monitoring model (Botvinick et al., 2001; 2004). If a conflict is detected in the current trial, the top-down control demand in the next trial is modulated.

In Experiment 4, false alarm response rate was lower after the incongruent trial than the congruent trial. According to the present model, this is explained by the top-down control demand that is higher after the incongruent trial than the congruent trial. Consequently, false alarm response would be more resistant to be executed after the incongruent trial. Furthermore, results of Experiment 5 showed that awareness of conflict is necessary for the modulation of top-down control demand. Therefore, this feedback-loop would be acting under the consciousness.

5.2.1.2 Sustained Modulation Based on Contingency Learning

Results of Experiments 1 and 3 suggest that the block-wise experience of frequent conflict guides utilization of the location-based response activation in a reversed manner. In this model, the sustained modulation is explained as the contingency learning between the correct response and the task-irrelevant location. In the connectionist network, simultaneous activation of cells leads to pronounced increases in synaptic strength between those cells; such a contingency learning is known as the Hebbian learning (Hebb, 1963; Verguts & Notebaert, 2008). Previous study has already mounted the Hebbian learning to connect correct response with the task-relevant activation (Verguts & Notebaert, 2008). In addition to that, the present findings show the importance of its connection with the task-irrelevant activation. In the Simon task, under the condition in which an experimental block contains an extremely large proportion of incongruent trials, a potential reactive bias toward responding with the hand opposite to the stimulus location may be generated as a result of experiencing a number of incongruent trials. This in turn may result in the reverse congruency effect, because such a binding between the stimulus location and the ‘counter-location’ response is more advantageous to the incongruent than congruent trials.

5.2.2 Adaptational Significance of the Dual Modulation Model

The dual modulation model proposed above embodies flexible adaptational ability that we demonstrate in our daily life. I try to make some tentative discussion on such an adaptational significance of the model.

First, as for its transient modulation mechanism, an important point is that it does not change the association strength between stimulus and response (S-R association), but makes the S-R association just temporally inactive. That should exactly have great adaptational significance. This is because the task-irrelevant information that must be ignored in the cognitive conflict tasks (e.g., location information in the Simon task) does indeed have an adaptational association in real life settings. For example, automatically triggering left-hand response to the stimulus presented on the left side is undoubtedly adaptational per se, since we do so very often in real life and it is almost always successful. Therefore, it should be rather unadaptational to change the strength of such an S-R association by experiencing only single failure on an incongruent trial in the experiment. Conversely, as a coping strategy to such an 'unusual' incident, it is more efficient way to temporally cut off the effect of the S-R association (via enhancing inhibitional loop by the cognitive control), while keeping the strength of existing S-R association at the certain level.

Next, an important feature of the sustained modulation mechanism is that it changes the strength of the S-R association slowly through unconscious contingency learning. As noted above, it is effective to cope with unusual cases in 'one-by-one' manner with keeping the S-R association intact, but when unusual cases occur repeatedly to make 'lasting environmental change' such a strategy should become ineffective. In other words, there is another necessity to equip us with a separate learning system to properly cope with sustained contextual change. Here, two restrictions should be considered; 1) such an additional system should not be too complicated nor resource-consuming, and 2) it should not cause so abrupt change. At these points, hypothesized mechanism in the present model, which is assumed to work on a simple rule without consuming much cognitive resource and modulates the whole system slowly, seems to be valid.

Taken these points together, the present model would have certain logical validity and strength of explanation for the empirical evidences found so far.

5.3 Limitations and Conclusions

5.3.1 Limitations in the Present Research

Finally, some limitations of the present model should be identified for future research. First, while the Simon task employed in the present study is characterized as a response congruency task, the sustained modulation of cognitive control has been observed in not only response congruency but also stimulus congruency tasks such as the flanker task (Gratton et al., 1992) and Stroop-like task (Logan & Zbrodoff, 1979). It remains unclear whether the response bias exhibited here also occurs in stimulus congruency tasks. In addition, response bias may be limited to the two-choice situation examined in this study. Therefore, further studies with various congruency tasks are necessary to generalize the present findings to a wider range of situations involving cognitive control.

Second, it is still not clear how the transient modulation mechanism and the sustained modulation mechanism interact under the sustained conflict context. The present model assumes that these two mechanisms are working together at all times, even though their influences are not always observed apparently. Therefore, in order to test the validity of the model and to make proper improvements, it is necessary to understand in more detail how these mechanisms interact under various situations. For doing this, examination with neurophysiological indices, as well as behavioral indices, would be effective, since an early cognitive processing that does not emerge as a behavior would be specifically important.

Third, a changing-over process from the initial ‘steady-state’ to the sustainedly-modulated state has also much to be investigated. Though the sustained modulation mechanism is considered to work *slow*, it is unknown *how slow* it is, or in other words, how the association strength changes as a function of the number of incongruent trials experienced. Furthermore, while the sustained conflict context examined in the experiments lasted for only several minutes, it is open to further discussion that the present findings would apply to the real world situation where the conflict may last for much longer. To see this problem from a different viewpoint, in the experimental situation, relative frequency of experience is unnaturally high, because many trials are given one after another with short interval. Thus, it would be another question to be answered which of temporal length and number of experience is more critical. To tackle these problems, further studies are needed with employing long-term conflict context, manipulating experiential frequency, and observing the degree of modulation that would change in a time course.

5.3.2 Concluding Remarks

In the present thesis, it was investigated whether the sustained and transient modulations are caused by the same underlying mechanism. Experiments 1 and 2 showed that both the transient and sustained modulation equally reflect changing of the process at the task-irrelevant route. Experiments 3 showed that the task-irrelevant route was closed in the transient conflict context. Contrasted to this, Experiment 4 showed that the task-irrelevant route was utilized based on the contingency learning of association between the task-irrelevant information and the response mapping in the sustained conflict context. Experiment 5 showed that awareness of the response conflict is necessary for the transient modulation, but not for the sustained modulation. In the general discussion, the dual modulation model was proposed based on the present empirical findings about differences between the transient and sustained modulations. In summary, according to this model, transient modulation was explained as the fast gating system, and sustained modulation as the additional slow learning system. Furthermore, it was discussed that these separate systems have adaptational merits of the dual 'fast and slow' modulation systems. In conclusion, the dual modulation system hypothesized here would be the most likely mechanism of the cognitive control, since it can specify the difference between the transient and sustained modulations, thereby explaining the reverse congruency effect.

References

Akçay, C., & Hazeltine, E. (2007). Conflict monitoring and feature overlap: Two sources of sequential modulations. *Psychonomic Bulletin and Review*, *14*, 742–748.

Bodner, G. E., & Dypvik, A. T. (2005). Masked priming of number judgments depends on prime validity and task. *Memory and Cognition*, *33*, 29–47.

Bodner, G. E., & Masson, M. E. (2001). Prime validity affects masked repetition priming: Evidence for an episodic resource account of priming. *Journal of Memory and Language*, *45*, 616–647.

Bodner, G. E., & Masson, M. E. J. (2003). Beyond spreading activation: An influence of relatedness proportion on masked semantic priming. *Psychonomic Bulletin and Review*, *10*, 645–652.

Bodner, G. E., & Masson, M. E. J. (2004). Beyond binary judgments: Prime validity modulates masked repetition priming in the naming task. *Memory and Cognition*, *32*, 1–11.

Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review*, *108*, 624–652.

Botvinick, M. M., Cohen, J. D., & Carter, C. S. (2004). Conflict monitoring and anterior cingulate cortex: An update. *Trends in Cognitive Sciences*, *8*, 539–546.

Botvinick, M. M., Nystrom, L. E., Fissell, K., Carter, C. S., & Cohen, J. D. (1999). Conflict monitoring versus selection-for-action in anterior cingulate cortex. *Nature*, *402*, 179–181.

Brainard, D. (1997). The psychophysics toolbox. *Spatial Vision*, *10*, 443–446.

Braver, T. S. (2012). The variable nature of cognitive control: A dual mechanisms framework. *Trends in Cognitive Sciences*, *16*, 106–113.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*. 2nd ed. Hillsdale, NJ:Lawrence Erlbaum Associates.

De Pisapia, N., & Braver, T. S. (2006). A model of dual control mechanisms through anterior cingulate and prefrontal cortex interactions. *Neurocomputing*, *69*, 1322–1326.

Dehaene, S., Bossini, S., & Giraux, P. (1993). The mental representation of parity and number magnitude. *Journal of Experimental Psychology*, *122*, 371–396.

Deroost, N., Vandenbossche, J., Zeischka, P., Coomans, D., & Soetens, E. (2012). Cognitive control: a role for implicit learning? *Journal of Experimental Psychology*, *38*, 1243–1258.

Desender, K., & Van den Bussche, E. (2012). Is consciousness necessary for conflict adaptation? A state of the art. *Frontiers in Human Neuroscience*, *6*, 3.

Egner, T. (2007). Congruency sequence effects and cognitive control. *Cognitive, Affective, and Behavioral Neuroscience*, *7*, 380–390.

Egner, T., & Hirsch, J. (2005). Cognitive control mechanisms resolve conflict through cortical amplification of task-relevant information. *Nature Neuroscience*, *8*, 1784–1790.

Fernandez-Duque, D., & Knight, M. (2008). Cognitive control: dynamic, sustained, and voluntary influences. *Journal of Experimental Psychology*, *34*, 340–355.

Fitts, P. M., & Seeger, C. M. (1953). S-R compatibility: Spatial characteristics of stimulus and response codes. *Journal of Experimental Psychology*, *46*, 199–210.

Francken, J. C., Gaal, S. V., & de Lange, F. P. (2011). Immediate and long-term priming effects are independent of prime awareness. *Consciousness and Cognition*, *20*, 1793–1800.

Funes, M. J., Lupiáñez, J., & Humphreys, G. (2010). Sustained vs. transient cognitive control: Evidence of a behavioral dissociation. *Cognition*, *114*, 338–347.

Gratton, G., Coles, M. G., & Donchin, E. (1992). Optimizing the use of information: Strategic control of activation of responses. *Journal of Experimental Psychology*, *121*, 480–506.

Hebb, D. O. (1963). *The Organization of Behavior*. New York: Wiley & Sons.

Hommel, B. (1998). Event files: Evidence for automatic integration of stimulus-response episodes. *Visual Cognition*, *5*, 183–216.

Hommel, B., Proctor, R. W., & Vu, K.-P. L. (2004). A feature-integration account of sequential effects in the Simon task. *Psychological Research*, *68*, 1–17.

Iani, C., Rubichi, S., Gherri, E., & Nicoletti, R. (2009). Co-occurrence of sequential and practice effects in the Simon task: Evidence for two independent mechanisms affecting response selection. *Memory and Cognition*, *37*, 358–367.

Jacoby, L. L., Lindsay, D. S., & Hessels, S. (2003). Item-specific control of automatic processes: stroop process dissociations. *Psychonomic Bulletin and Review*, *10*, 638–644.

Kerns, J. G., Cohen, J. D., MacDonald, A. W., Cho, R. Y., Stenger, V. A., & Carter, C. S. (2004). Anterior cingulate conflict monitoring and adjustments in control. *Science*, *303*, 1023–1026.

Kinoshita, S., Forster, K. I., & Mozer, M. C. (2008). Unconscious cognition isn't that smart: Modulation of masked repetition priming effect in the word naming task. *Cognition*, *107*, 623–649.

Kornblum, S., Hasbroucq, T., & Osman, A. (1990). Dimensional overlap: Cognitive basis for stimulus-response compatibility—a model and taxonomy. *Psychological Review*, *97*, 253–270.

Kunde, W. (2003). Sequential modulations of stimulus-response correspondence effects depend on awareness of response conflict. *Psychonomic Bulletin and Review*, *10*, 198–205.

Lindsay, D. S., & Jacoby, L. L. (1994). Stroop process dissociations: The relationship between facilitation and interference. *Journal of Experimental Psychology*, *20*, 219–234.

Logan, G. D., & Zbrodoff, N. J. (1979). When it helps to be misled: Facilitative effects of increasing the frequency of conflicting stimuli in a Stroop-like task. *Memory and Cognition*, *7*, 166–174.

Lu, C.-H., & Proctor, R. W. (1995). The influence of irrelevant location information on performance: A review of the Simon and spatial Stroop effects. *Psychonomic Bulletin and Review*, *2*, 174–207.

MacDonald, A. W., Cohen, J. D., Stenger, V. A., & Carter, C. S. (2000). Dissociating the Role of the Dorsolateral Prefrontal and Anterior Cingulate Cortex in Cognitive Control. *Science*, *288*, 1835–1838.

Mayr, U., & Awh, E. (2009). The elusive link between conflict and conflict adaptation. *Psychological Research*, *73*, 794–802.

Monsell, S., & Driver, J. (2000). *Control of Cognitive Processes*. London: MIT Press.

Musen, G., & Squire, L. R. (1993). Implicit learning of color-word associations using a Stroop paradigm. *Journal of Experimental Psychology*, *19*, 789–798.

Notebaert, W., & Verguts, T. (2008). Cognitive control acts locally. *Cognition*, *106*, 1071–1080.

Ridderinkhof, K. R. (2002). Micro- and macro-adjustments of task set: Activation and suppression in conflict tasks. *Psychological Research*, *66*, 312–323.

Ryan, T. (1960). Significance tests for multiple comparison of proportions, variances, and other statistics. *Psychological Bulletin*, *57*, 318–328.

Schmidt, J. R. (2013). Questioning conflict adaptation: Proportion congruent and Gratton effects reconsidered. *Psychonomic Bulletin and Review*, *20*, 615–630.

Schmidt, J. R., & Besner, D. (2008). The Stroop effect: Why proportion congruent has nothing to do with congruency and everything to do with contingency. *Journal of Experimental Psychology*, *34*, 514–523.

Simon, J. R., Sly, P. E., & Vilapakkam, S. (1981). Effect of compatibility of S-R mapping on reactions toward the stimulus source. *Acta Psychologica*, *47*, 63–81.

Stürmer, B., Leuthold, H., Soetens, E., Schröter, H., & Sommer, W. (2002). Control over location-based response activation in the Simon task: Behavioral and electrophysiological evidence. *Journal of Experimental Psychology*, *28*, 1345–1363.

van Gaal, S., Lamme, V. A. F., & Ridderinkhof, K. R. (2010). Unconsciously triggered conflict adaptation. *PLoS ONE*, *5*, e11508.

van Gaal, S., Ridderinkhof, K. R., Fahrenfort, J. J., Scholte, H. S., & Lamme, V. A. F. (2008). Frontal cortex mediates unconsciously triggered inhibitory control. *Journal of Neuroscience*, *28*, 8053–8062.

van Gaal, S., Ridderinkhof, K. R., van den Wildenberg, W. P. M., & Lamme, V. A. F. (2009). Dissociating consciousness from inhibitory control: Evidence for unconsciously triggered response inhibition in the stop-signal task. *Journal of Experimental Psychology*, *35*, 1129–1139.

Verguts, T., & Notebaert, W. (2008). Hebbian learning of cognitive control: Dealing with specific and nonspecific adaptation. *Psychological Review*, *115*, 518–525.

Wendt, M., Kluwe, R. H., & Peters, A. (2006). Sequential modulations of interference evoked by processing task-irrelevant stimulus features. *Journal of Experimental Psychology*, *32*, 644–667.