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Modality Switching Within Conditional Reasoning

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Abstract

The format in which humans represent knowledge is still not known. Two perspectives that explain the way in which humans represent knowledge are the amodal and modal perspectives. Recently, a modality switching effect was found during a property verification task. The modality switching effect is a delay in response time in verifying the property of an object in a modality that is different from the previously verified property of a different object. This effect is often presented as evidence to support the modal perspective, but it has not been found in a task more complex than property verification. The goal of this study was to examine whether the modality switching effect would be found when evaluating conditional reasoning problems (as in, If P then Q; P/Q). The modality switching between the clauses (P & Q) of the first premise (If P then Q) of a conditional reasoning problem was manipulated to either switch or non-switch. Reading times of the second clause (Q), which either did or did not switch when compared to the first clause (P) were measured. The results indicated that modality switching did not affect reading time when evaluating conditional reasoning problems. However, an unexpected interaction was found between modality switching and reasoning type, the implications of which are further discussed.

Modality Switching within Conditional Reasoning

We use the knowledge we have stored every day to help us understand the world around us and to interact with it. Knowledge representation, referring to the way knowledge is stored, has been a topic of interest for cognitive scientists for centuries. Philosophers such as John Locke have wondered about the fundamental nature of knowledge, and in what way it gets stored for later use. Yet, we still do not precisely know the format in which we store knowledge.

Understanding the format of the represented knowledge is beneficial in several ways. For instance, a greater understanding of the format that knowledge takes can lead to advances in our understanding of areas within psychology such as learning, cognitive processes, and development. Consequently, we can better develop strategies to improve our education system. An example of one improvement that could be made is in the presentation of information to students. If students are able to more easily process and comprehend what is presented then they might be able to retain more information. The current study tried to expand on what is already known about the format of human knowledge in order to possibly provide insight into areas that can benefit from understanding the format of human knowledge representation.

There are at least two main perspectives on how the information that forms our knowledge base is formatted. The first perspective, known as the amodal perspective, suggests that human knowledge consists of abstract mental structures, is conceptual, and is non-sensory (Pylyshyn, 1973; 2003). The alternate perspective, known as the modal perspective, proposes that human knowledge resides within the sensory-motor systems of the brain (Barsalou, 1999). Recently a phenomenon known as modality switching effect (MSE) has been found during a property verification task and is used as support for the modal perspective (Pecher, Zeelenberg & Barsalou, 2003). Property verification is a task in which a participant verifies if the property of a

concept is true or not. An example of an item from property verification would be, *the sky can be blue,* where *blue* is the property being verified of the concept *sky*. MSE is a delay in response time when verifying the property of a concept that differs in modality from the property of the previous concept (Pecher et al., 2003). For instance, in the phrases, *the sky can be blue; the lemon can be smooth,* each concept (i.e., *sky and lemon*) has a property from a different modality (i.e., *blue; visual, and smooth; tactile*). As a result of the second property being switched from the first, a modality switching cost would occur. This finding is predicted to occur according to the modal but not the amodal perspective of knowledge representation. Additional research has yet to conclude whether or not the same modality switching effect occurs in tasks other than property verification.

Although it is true that this finding shows support for the modal perspective, further questions about the nature of this phenomenon have yet to be answered. For example, is the modality switching effect found in a task more complex than property verification? Dandotkar and Wiemer (2008) tried to answer this question by using conditional reasoning problems to increase the complexity of the task, and therefore the cognitive demand on the participants. In their study, participants evaluated conditional reasoning problems of the sort, "if p then q, p therefore q." The researchers manipulated the modalities of the constructs in the clauses p and q in premise 1 (if p then q) of the problem to be of the same (non-switch) or different (switch) modalities. Participants evaluated whether the conclusion (as in "therefore q") was valid given the premises. Time taken to respond to the conclusion was measured. This study did not find an effect of modality switching in the conditional reasoning task. However, as a result of measuring response time at the conclusion, the effect of modality switching could have been lost due to the subtlety of modality switching effect. Consequently, further research needs to be done to

determine whether or not task complexity could be a factor in finding a modality switching effect or not within conditional reasoning.

The current study explores whether modality switching effects can be found in a task more complex than property verification. Additionally, this study seeks to discover if measuring reading times at an earlier point during the evaluation of conditional reasoning problems will reveal different data than was previously found in the same conditional reasoning task when measuring at the conclusion. The conflicting hypotheses of the amodal and modal perspective of knowledge representation predict different outcomes for the possible results of this study. A review of the details about each of these perspectives and a recently discovered phenomenon known as modality switch effect will now be presented to illustrate the differing views about the nature of knowledge representation.

Perspectives of the Format of Human Knowledge

We use the knowledge we have stored every day to help us understand the world around us. Yet, we still do not know in what way we store that knowledge. One perspective that explains the way in which humans store knowledge is the amodal perspective. Theories based on this perspective assume that knowledge is stored abstractly (Pylyshyn, 1973; 2003). One way to think about the amodal perspective's view of knowledge representation is how a computer stores information. Just like a computer stores information in 1's and 0's, but those number combinations do not correspond to what is shown on the screen. Likewise, people store knowledge abstractly but those abstract representations do not correspond to what is perceived, according to the amodal perspective. For example, according to the amodal perspective, when people see a chair they store information about that chair in terms of its details, like a feature list

(e.g. legs, seat, and back). Due to the assumption that knowledge is represented abstractly, this perspective also assumes that knowledge is represented non-pictorially (1973; 2003).

One other perspective that is particularly related to this paper is the modal perspective. This perspective assumes that knowledge is stored perceptually and that it resides in the perceptual systems of the brain (Barsalou, 1999; 2007). According to this perspective, knowledge is stored pictorially. This means the knowledge that is stored is directly linked to what is perceived in the environment. As an extension of the earlier example, when people see a chair they store an image of that chair for a later use. The details and differences of both perspectives are discussed further in the upcoming sections.

Amodal Perspective

Since advances in computer science and mathematics during the time of the cognitive revolution, the amodal perspective has been the traditional way of thinking about the format of human knowledge because of how it can explain psychological phenomena through such constructs as semantic networks, feature lists, and predicate calculus sentences (Barsalou, 1999; Pylyshyn 2003). According to the amodal perspective, knowledge is represented abstractly. In other words, knowledge is not pictorial. Therefore, only abstract representational structures and conceptualizations are being manipulated to form thought.

One implication of this assumption is that perceptual and motor systems are not utilized either when storing or retrieving information from the represented knowledge (Pylyshyn, 2003). Accordingly, knowledge is not directly linked to what is perceived. Although the amodal perspective is a traditionally adopted perspective of knowledge representation, there are other perspectives that have recently gained attention in the field. One such perspective is the modal perspective.

Modal Perspective

According to the modal perspective, knowledge is grounded in the sensory-motor areas of the brain (Barsalou, 1999). Grounding refers to the connection between what is represented in our heads and what is perceived (Barsalou, 2008; Harnad, 1990). For instance, the representation of "cup" is not connected to the object "cup" that is in the world, unless it is grounded. This perspective proposes that sensory-motor systems are utilized to ground the representation of cup by storing the perceived event of the object "cup" within the sensory-motor areas of the brain (Barsalou, 1990). The result of storing knowledge in the sensory-motor areas is that the knowledge that is represented within the knowledge system is directly linked to what is perceived (Barsalou, 2008; Harnad, 1990).

According to the simulation theories (Hesslow, 2002), which is a modal perspective theory, thinking is a process of manipulating perceptual representations that are stored in the sensory-motor areas of the brain. In other words, the sensory motor areas get activated when we think. For example, when conceptually processing information, as in verifying the property of an object (*the sky can be blue*), the sensory-motor areas of the brain are activated.

Neurological evidence has supported the modal perspective's implication that sensory-motor areas are used for conceptual processing. Brain imaging has shown that when a participant grabs a hammer the same parts of the brain are activated when reading about grabbing a hammer. In addition, recent evidence has also been thought to support this idea. One phenomenon that is used in support of the modal perspective is the modality switch effect (Pecher et al., 2003).

A modality switch effect is a delay in response time to the second property in a sequence of concept and property pairs when the modalities of the properties are switched (Pecher et al., 2003). For example, *the sky can be blue, the apple can be smooth*, these two sentences switch

modalities of their properties and it could be guessed that a modality switch effect would occur due to the switching. Blue is a visual modality, while smooth is a tactile modality. If the second sentence was of the same modality as the first sentence then the response would be quicker than the pair that was switched. For example, *the sky can be blue, the apple can be red*, and this pair would more than likely have a quicker response time at the second concept and property pair. Two studies will now be presented to show what evidence has been found relating to this effect and what it means regarding knowledge representation.

Researchers found that a modality switch effect occurs when perceiving and conceptualizing in different modalities (Dantzig, Pecher, Zeelenberg, & Barsalou, 2008). The researchers explored the idea that a perceptual task could affect concept representation. The results indicated that when switching from perceiving stimuli to property verification, a modality switching cost occurred. According to the researchers, this means perceptual and conceptual systems are at least somewhat overlapped. The modal perspective's assumption that sensory-motor systems are used for knowledge representation is supported by the results of this study, as opposed to the amodal perspective, which does not account for this result.

In addition to a modality switch effect being found in a perceptual to a conceptual task, it was also found in a task solely manipulating modality switching within a conceptual task (Pecher, Zeelenberg, & Barsalou, 2003). The researchers explored the idea within the modal perspective that conceptual processing uses sensory-motor systems. The goal was to investigate this idea by using a property verification task. Property verification was used so that the researchers could measure whether verifying the second property, in a sequence of concept-property pairs, had a cost of switching modalities between properties. In both the first and second experiment the participants read sentences one at a time and then responded when done reading.

The difference between the two experiments was that the first experiment contained stimulus onset asynchrony between the presentation of the concept and the presentation of the property. The second experiment presented the concept and property at the same time. The modality switching condition was manipulated between same (non-switch) and different (switch) modalities. Response time was measured at the time of the presentation of the second property in the sequence of the concept property pairs. The results of both experiments were that a modality switching cost occurred in both experiments during the switch condition of modality switching. This means that it took participants a significantly longer amount of time when properties were switched (Pecher et al., 2003). According to the researchers of this study, the results indicate that modality-specific simulations are taking place during the task, and the modal perspective assumes this to happen in conceptual processing. Although both of these studies found an effect of modality switching, neither experiment used a task more complex than property verification.

Task Complexity

Modality switching costs have not been found in a task other than property verification. One study that sought to answer whether a modality switching cost could be found in a complex task was Dandotkar and Wiemer (2008). The researchers examined whether the modality switching effect would be observed within a conditional reasoning task. The participants read conditional reasoning problems and then responded to the conclusion to answer whether or not the conclusion was valid or invalid. The researchers manipulated the modality switching condition and the reasoning type condition within the experiment. Response time at the conclusion of each conditional reasoning problem was measured. The results of the experiment indicated that modality switching did not cause response times to be slower or faster. This result is different than what was found in the property verification task. The implication of these

findings is that modality switching may have no effect on the response time at the conclusion of conditional reasoning problems.

One possible reason why the modality switch effect is found in property verification and not in conditional reasoning could be related to the complexity of the task. It could be that the modality switch effect is task dependent. In other words, we may have at least two different types of representations. The pictorial representations, on the one hand, could be used in simple tasks such as property verification, which would be in agreement with the modal perspective. As opposed to the non-pictorial representations, which could be used in complex tasks like conditional reasoning, which would be in line with the amodal perspective. Another possibility could be that the modality switching effect is task-independent. In other words, it should be found in both simple and complex tasks. This could be due to the subtlety of the modality switch effect and it may not have been captured by the time the conclusion was reached because of the switch taking place in the first premise and also the conclusion. For example, *If the sky is blue, then the apple is smooth, the sky is blue, therefore the apple is smooth*, this conditional reasoning problem has a switch between the first two and last two sentences. If only the conclusion is measured it could be possible that the initial modality switch effect is lost and confounds the second one. This leads to the idea that measuring reading time during a different part of the conditional reasoning problem may help capture the modality switching effect found previously in a property verification task.

Overview of the Current Study

The current study examined whether modality switching effects the reading times during the evaluation of conditional reasoning problems. Furthermore, this study seeks to discover whether or not recording response times earlier in a conditional reasoning task than Dandotkar

and Wiemer (2008) will provide similar results to those discovered in Pecher et al. (2003). During the experiment, the participants read conditional reasoning problems clause by clause until they reached the conclusion. Once the conclusion was reached, the participants responded by indicating whether they thought the conclusion was valid or invalid. Modality switching was manipulated to be either same (non-switch) or different (switch) in each conditional reasoning problem. Likewise, reasoning type was manipulated to make the reasoning problems one of four reasoning types (Denying the antecedent, Modus Tollens, Affirming the consequent, and Modus Ponens). After each participant read clause 2 of the conditional reasoning problems, the reading time was recorded.

There were two competing hypotheses that were tested in the current study. The *modal hypothesis*, predicts a main effect of modality switching. This hypothesis, based on the modal perspective, assumes that knowledge is represented within the sensory-motor systems of the brain. Consequently, a switching in modality should increase the reading time. In short, a switching effect should be found in complex tasks because the response time is measured between clauses of the first premise rather than at the conclusion.

The *amodal hypothesis*, on the other hand, predicts that there would not be a modality switching effect. This hypothesis is based on the assumption that knowledge is stored in non-perceptual systems in an abstract style. As a result, sensory-motor areas should not be involved. Neither hypothesis predicts an interaction effect between the modality switching condition and the reasoning type condition that this experiment manipulates. If modality switching costs are found in this experiment, they should be similar to what was found previously in property verification.

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Method

Participants

35 undergraduates (27 females & 8 males) from Eastern Illinois University participated for course credit and an incentive of a 10-dollar prize to increase motivation during the task. Block randomization method was adopted to randomly assign participants to one of the two lists of reasoning problems.

Materials

Ninety-six experimental modal conditional reasoning problems were used from Dandotkar and Wiemer (2008). These reasoning problems were created from the materials used in Pecher et al. (2003), by creating if – then statements with the concept and property pairs used in the property verification task.

Additionally, 96 non-modal conditional reasoning problems were used from Dandotkar and Wiemer (2008). These reasoning problems did not consist of concept and property pairs, but only single letters. These items were randomly placed in between the experimental items in order to keep the effects of one modal reasoning problem separate from another modal reasoning problem.

The two lists of conditional reasoning problems that were used were created by Dandotkar and Wiemer (2008). These lists included 3 types of modalities: Auditory (A), tactile (T), and visual (V). The lists contained three types of problems that are considered to be included in the non-switch condition. The modalities used in the non-switch condition are AA, TT, and VV. They also contained three types of problems that are considered to be included in the switching condition. The modalities used in the switch condition are AT, TV, AV. Therefore, in each list there are 8 conditional reasoning problems for each of the different modality pairs used

in the study. Table 1 presents an example of Clauses 1 and 2 of a possible conditional reasoning problem that would be used and illustrates the switch and non-switch conditions.

Table 1.

Example Item Presented for the Switch and Non-Switch Conditions.

Modality Switch	Premise 1 Clauses	Item
	Clause 1 (Visual)	If the apple is red
Switch	Clause 2 (Tactile)	Then the lemon is smooth
Non-Switch	Clause 2 (Visual)	Then the sky is blue

Additionally, the type of reasoning problem was a factor that this study explored. This factor helped to bring more complexity to the task. The 4 reasoning types were as follows: Denying the antecedent (DA), Modus Tollens (MT), Affirming the Consequent (AC), and Modus Ponens (MP). Refer to Table 2 for examples of the reasoning types. In each list there were an equal number of conditional reasoning problems for each type of reasoning.

Furthermore, syllable count was taken into consideration. At the second clause the syllables were counted for each conditional reasoning problem. The mean number of syllables for clause 2 of the conditional reasoning problems was; clause 2: $M = 6.19$, $SD = 1.30$.

Table 2.

Example of the Reasoning Types that are used in the Experiment.

Reasoning type	Example
Denying the antecedent (DA)	If P then Q; -P/ -Q
Modus Tollens (MT)	If P then Q; -Q/ -P
Affirming the Consequent (AC)	If P then Q; Q/ P
Modus Ponens (MP)	If P then Q; P/ Q

Design and analysis

The current study was a 2 (Modality Switching: Switch, Non-Switch) x 4 (Reasoning type: DA, MT, AC, MP) within-subjects design with both modality switching and reasoning type as within-participant factors. One repeated measures analysis of variance was conducted on the reading time per syllable.

Procedure

Each participant was asked to sign in and then was directed to sit at the first of three available computers. The computers were already set up with which list was randomly assigned to be open at each individual computer. Once participants sat down they were given a consent form to give their consent to participate in the study. Instructions were then explained out loud by the researcher. Afterwards, participants turned on the computer monitors and were asked to read the instructions themselves to insure familiarity with the experiment.

The software PsychoPy was used to present conditional reasoning problems (Pierce, 2007). First, the participants completed 4 practice conditional reasoning problems to familiarize them with the task, and then the experimental task began. When reading a problem, participants were instructed to press the "space bar" as soon as they were done reading each individual sentence in order to move on to the next sentence of the problem. When the conclusion was reached, participants were asked to press either the "T" key labeled key (The "F" key on the keyboard) to indicate that they believed the conclusion was valid based upon the previous sentences they read. If the participants believed that the conclusion was invalid, the participants were asked to press the "F" (The "J" key on the keyboard) labeled key. Participants were asked to be as quick and as accurate as possible and to keep their fingers on the "T" and "F" labeled keys during the entire time of the experiment. PsychoPy recorded the participants' reading times after each click of the "space bar" and the response time after each judgment at the conclusion with the press of the "T" or "F" labeled keys.

Results

Eight participants' data were dropped from the analyses because it was believed based upon the data that they may have not been reading the sentences. This was believed because each of these participants responded in fewer than 500 milliseconds. All other participants had 0 responses in fewer than 500 milliseconds. A total of 27 participants remained after the 8 participants were dropped from the analysis. In addition, 26 observations were found to be 3 standard deviations above the mean (M = .951, SD = .161). This accounted for 2.01% of the total observations. The analysis excluded those 26 observations.

In order to analyze the data and compare all reading times with each other, the syllables in each Clause 2 were taken into account. The reading times that PsychoPy recorded were then

divided by the number of syllables in the Clause 2 that was read. Therefore, the data that were analyzed were reading time per syllable.

A 2 Modality Switching (Switch vs. Non-Switch) X 4 Reasoning type (DA, MT, AC, MP) repeated-measures ANOVA was conducted with both switch and reasoning type as within participant factors, and reading time per syllable as the dependent measure. A summary of the results of the ANOVA is found in Table 3. Table 4 presents the mean reading times per syllable for each condition. At an alpha level of .05, the analysis generated a significant interaction effect between modality switching and reasoning type, $F(3, 78) = 2.868$, $MSE = .005$, $p < .05$, $\eta^2 = .099$, indicating that both the modality switching condition and reasoning type played a role in how long it took for participants to read. Further analyses answering more complex research questions are still ongoing. Figure 1 illustrates the interaction found. No other findings were found to be statistically significant.

Table 3.

ANOVA Summary Table

Sources of Variance	*SS*	*df*	*MS*	*F*	*p*	*Partial Eta Squared*	*Power*
Main Effect of Modality Switching	<.001	1	<.001	.022	.882	.001	.052
Residual (Modality Switch)	.058	26	.002				
Main Effect of Reasoning type	.003	3	.001	.647	.587	.024	.180
Residual-Reasoning type	.128	78	.002				
Interaction Effect	.015	3	.005	2.87	.042	.099	.665
Residual-Interaction	.136	78	.002				

Table 4.

Mean Reading Time Per Syllable and Standard Deviation at Clause 2 for Each Condition

Switch condition	Reasoning type			
	DA	MT	AC	MP
Non-Switch	.27 (.07)	.25 (.08)	.28 (.07)	.26 (.06)
Switch	.27 (.07)	.28 (.09)	.26 (.07)	.26 (.08)

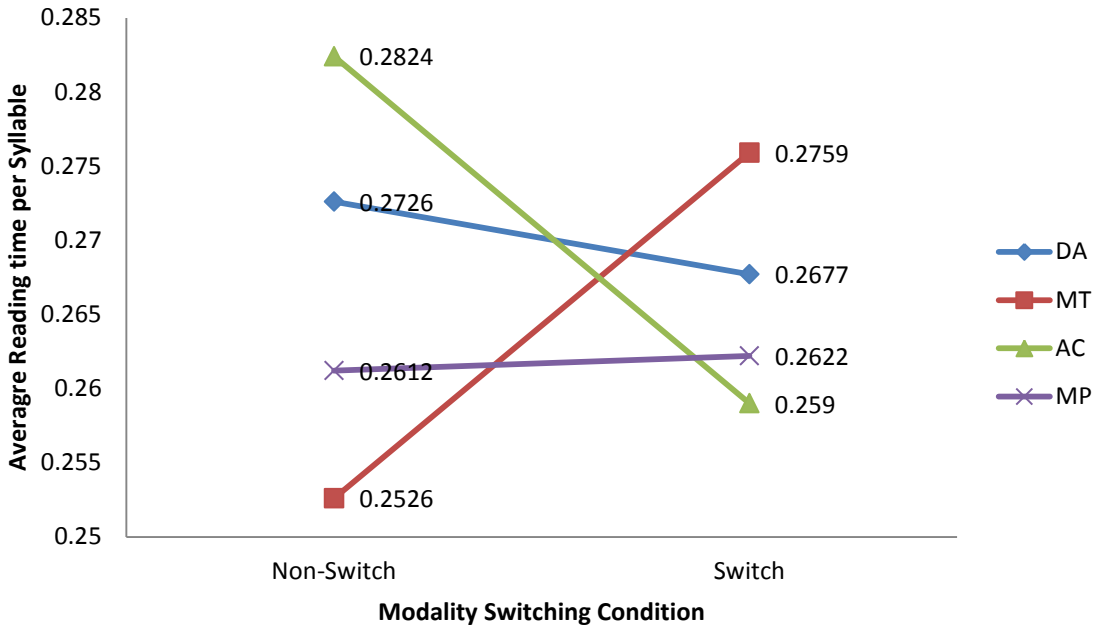

Figure 1. Mean Reading Time per Syllable at Clause 2 for Each Condition

Discussion

The goal of this study was to examine whether modality switching between conditional reasoning problems would affect the reading times of the clauses when evaluating the problems. Specifically, the current experiment examined the effect of modality switching within the first two clauses of 4 different types of conditional reasoning problems. The results indicated that there was no effect of modality switching. Likewise, there was no effect of reasoning type. However, an interaction between modality switching and reasoning type was found. The remaining section discusses the findings related to the hypotheses.

There were two competing hypotheses that were tested in the current study. The *modal hypothesis*, predicted an increase in the reading time for clauses that were switched in modality compared to those that were not switched. This hypothesis is based on the modal perspective, which assumes that knowledge is represented within sensory-motor systems of the brain.

The amodal hypothesis, on the other hand, predicted that there would not be a modality switching effect. This hypothesis is based on the assumption that non-sensory and abstract structures are used to represent knowledge. The results of the current study found that there was no effect of modality switching. In other words, there was no difference in reading time between switched and non-switched items. This finding supports the amodal hypothesis that abstract representations are used during conceptual processing and does not support the modal perspective.

This result is different than what was found previously when the modality switch effect was found to occur when properties were verified (Pecher et al., 2003). However, it did not occur within the first 2 clauses of the conditional reasoning problems that this study used. A possible explanation of the differing results could be that task complexity mediates what type of

representation is used. In other words, simple tasks may use pictorial representations, and complex tasks use non-pictorial representations.

Despite the fact that both perspectives differ in their hypotheses and their predictions relating to modality switching, neither hypothesis predicts any significant findings relating to reasoning type within the first two clauses. In line with both hypotheses, there was no effect of reasoning type on the reading times when evaluating conditional reasoning problems at the second clause. In short, this means that there was no difference in reading times among the 4 reasoning types.

However, reasoning type was found to have an effect on the response times of the judgments of the conclusions in an earlier study (Dandotkar & Wiemer, 2008). Reasoning type may have been a factor in this study due to the fact that the response times were recorded at the conclusion rather than the reading times at clause 2. Once the conclusion is reached, the reasoning type is fully developed within the problem, whereas at Clause 2 it has not.

Similarly, neither hypothesis predicted an interaction between modality switching and reasoning type. However, an interaction between these 2 factors was found. An alternate perspective could explain the results found here. This perspective is a combined or dual perspective including both amodal and modal representations to be manipulated in knowledge representation. One theory that can be included within this type of perspective is dual-coding theory (DCT).

DCT is one theory that has been proposed that includes both modality specific and nonverbal representations (Paivio, 1971; 1986; Clack & Paivio, 1991). Therefore, this theory includes both the proposed representations, that is, the abstract from the amodal perspective and the perceptual from the modal perspective. Each type of representation is used differently and

can be used together in tasks. This combined perspective might help explain the current results from the analysis because modality switching may occur in some tasks but not others.

A possible explanation could be that the complexity of the task may mediate whether or not one type of representation is used more or less, or possibly not at all compared to the other type. This is a possible explanation of the results found here due to the fact that a modality switching cost was found previously in property verification (Pecher et al., 2003). It could be that the switch condition then caused an increase or decrease in reading time based upon the difficulty of the reasoning type of the problem that the participant read. Granted, this study does not yet have a conclusive explanation for this possibility due to the fact that the reasoning type was not yet developed at the point when reading time was measured.

Limitations

One limitation of this study is that it did not take into account the difference in materials between the property verification task and the conditional reasoning task. A difference in materials could cause a difference in capturing the modality switch effect. Once both the tasks are conducted with the same materials then a comparison could be made between the findings of the current study and that of the property verification studies.

Another limitation could be that conditional reasoning is not the best task to capture a modality switch effect. A different task that shares the same complexity as conditional reasoning may be able to capture the modality switch effect. Once another complex task is used to try to capture the modality switch effect, it could be determined whether conditional reasoning is a sufficient enough task to try to capture the modality switch effect or not.

Future Directions

In the future, studies could explore questions relating to the number of formats of human knowledge and other tasks that could be used. Future studies could explore the possibility that there are at least two formats of human knowledge. Specifically, future research could test among the modal, amodal, and dual-coding theories of knowledge representation. Similarly, these theories could be tested across other complex task domains. More research is needed in this area in order to further understand the nature of knowledge representation.

Conclusions

The current study, unlike the previous studies that looked at simpler tasks, suggests that modality switching does not affect the reading times when evaluating conditional reasoning problems. Furthermore, the current study suggests that modality switching effect is usually not found under complex tasks like conditional reasoning problems, even when the reading time was measured in the first premise. It seems like modality switching occurs in some tasks, but not in other more complex tasks such as conditional reasoning. However, the interaction between the reasoning type and modality switching that the current study found raises some interesting questions about the nature of knowledge representation.

Also, the possible explanation given for the current study's results leads to interesting questions about the format that knowledge is represented in. If complexity does mediate the representations used in a task, then that would be an intriguing finding and deserves additional exploration in future studies. The current study's findings related to the potential mediating effect of task complexity on modality switch effect allude to a possibility where knowledge is represented in both an abstract and a perceptual format. Answering the questions relating to the

modality switching and task complexity that this study has brought forth could potentially benefit the educational system in general and students in particular.

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Appendix A.

Instructions Presented

Appendix A.

Instructions Presented

Welcome to the experiment!

You will be reading reasoning problems presented on the computer, one at a time. Each reasoning problem consists of two or three sentences followed by a conclusion. Read each sentence quickly and carefully and press the "Space Bar" on the keyboard when you have finished reading each sentence. When you reach the conclusion, you need to decide if the conclusion is valid given the previous two or three sentences. If you think that the conclusion is valid, please press the "T" labelled key on the keyboard and if you think that the conclusion is invalid, please press the "F" labelled key on the keyboard.

Please respond to the conclusion as accurately and as quickly as you possibly can. It is very important that you pay full attention during the experiment. For the same reason, we want you to keep your right index finger on the "Y" labelled key and left index finger on the "F" labelled key ALL THROUGH THE TIME. Please do not take a break at any time during the experiment.

First you will go through a practice session followed by the actual experiment. Please feel free to contact the experimenter if you have any questions. Otherwise proceed with the actual experiment. Your focused and serious participation is very important and very valuable to us. We sincerely appreciate it.

(Practice session began)

Appendix A.

Instructions Presented (Continued)

This ends the practice session. You are about to start the actual experiment. Please contact the experimenter if you have any questions. You may take a break at this point. Make sure you keep your index fingers on the “T” and “F” labelled keys all throughout the experiment and also make sure you are attentive and focused through the experiment. Please press the space bar when you are ready. Thank you for your time and attention. We appreciate it.

Appendix B.

List 1 of Modal Conditional Reasoning Problems

Appendix B.

List 1 of Modal Conditional Reasoning Problems

Clause1	**Clause2**	**Premise 2**	**Conclusion**
If the cricket chirps	then the snake hisses	The cricket did not chirp	Therefore the snake did not hiss
If the scooter hums	then the station hall is noisy	The scooter hummed	Therefore the station hall is noisy
If the airplane is loud	then the bicycle bell rings	The bicycle bell did not ring	Therefore the airplane is not loud
If the triangle jingles	then the dog barks	The dog barked	Therefore the triangle jingled
If the railroad crossing rings	then the siren wails	The siren did not wail	Therefore the railroad crossing did not ring
If the alarm beeps	then the fly buzzes	The alarm did not beep	Therefore the fly did not buzz
If the rooster crows	then the church organ clangs	The rooster crowed	Therefore the church organ clanged
If the truck honks	then the doorbell rings	The doorbell rang	Therefore the truck honked
If the cassette tape is black	then the shirt is striped	The shirt is striped	Therefore the cassette tape is black
If the chocolate is dark brown	then the cellar is dark	The cellar is not dark	Therefore the chocolate is not dark brown
If the razorblade is silver	then the eggplant is dark purple	The razorblade is not silver	Therefore the eggplant is not dark purple
If the leopard is spotted	then the night is dark	The leopard is spotted	Therefore the night is dark
If the spinach is dark green	then the ice cube is transparent	The ice cube is not transparent	Therefore the spinach is not dark green
If the water is muddy	then the chessboard is checkered	The water is not muddy	Therefore the chessboard is not checkered

Appendix B.

List 1 of Modal Conditional Reasoning Problems (Continued)

Clause1	Clause2	Premise 2	Conclusion
If the table-top is oval	then the inner tube is black	The inner tube is black	Therefore the table-top is oval
If the tennis ball is yellow	then the bridge is curved	The tennis ball is yellow	Therefore the bridge is curved
If the marble is rock hard	then the sand is gritty	The sand is not gritty	Therefore the marble is not rock hard
If the light bulb is very hot	then the coin is hard	The coin is hard	Therefore the light bulb is very hot
If the teapot is warm	then the cave is chilly	The teapot is not warm	Therefore the cave is not chilly
If the snowball is cold	then the bone is hard	The snowball is cold	Therefore the bone is hard
If the sand can grind	then the mosquito bite itches	The mosquito bite itched	Therefore the sand can grind
If the wound hurts	then the cotton candy is sticky	The wound hurt	Therefore the cotton candy is sticky
If the bed is spongy	then the eraser is rough	The eraser is not rough	Therefore the bed is not spongy
If the toast is warm	then the bee stings	The toast is not warm	Therefore the bee did not sting
If the pans clang	then the squirrel is red-brown	The pans did not clang	Therefore the squirrel is not red-brown
If the boy gurgles	then the floor is mottled	The floor is not mottled	Therefore the boy did not gurgle
If the autumn leaves rustle	then the orca is black-and-white	The autumn leaves rustled	Therefore the orca is black-and-white

Appendix B.

List 1 of Modal Conditional Reasoning Problems (Continued)

Clause1	**Clause2**	**Premise 2**	**Conclusion**
If the high heels tap	then the car is blue	The car is blue	Therefore the high heels tapped
If the tram grinds	then the walnut is brown	The walnut is brown	Therefore the tram ground
If the brushwood crackles	then the peppermint is white	The brushwood did not crackle	Therefore the peppermint is not white
If the saxophone blares	then the butter is yellowish	The butter is not yellowish	Therefore the saxophone did not blare
If the flute is high-pitched	then the honey is golden-yellow	The flute is high-pitched	Therefore the honey is golden-yellow
If the 38mayonnaise is light yellow	then the ant tickles	The ant tickled	Therefore the 38mayonnaise is light yellow
If the hair is short	then the shoe is tight	The hair is not short	Therefore the shoe is not tight
If the wasp is striped	then the candy is sticky	The wasp is striped	Therefore the candy is sticky
If the ham is pink	then the toy is soft	The toy is not soft	Therefore the ham is not pink
If the jellyfish is translucent	then the feather tickles	The jellyfish is translucent	Therefore the feather tickled
If the swimming pool is azure blue	then the iron is hot	The iron is not hot	Therefore the swimming pool is not azure blue
If the diamond glistens	then the bath water is lukewarm	The bath water is lukewarm	Therefore the diamond glistened
If the broccoli is green	then the rain is fresh	The broccoli is not green	Therefore the rain is not fresh
If the ship’s horn is low-pitched	then the fingers tingle	The ship’s horn is low-pitched	Therefore the fingers tingled

Appendix B.

List 1 of Modal Conditional Reasoning Problems (Continued)

Clause1	**Clause2**	**Premise 2**	**Conclusion**
If the music is jarring	then the dress is velvety	The music is not jarring	Therefore the dress is not velvety
If the trumpet sounds shrill	then the waterfall is cool	The waterfall is not cool	Therefore the trumpet did not sound shrill
If the lion roars	then the iodine stings	The iodine stang	Therefore the lion roared
If the alarm clock ticks	then the shawl itches	The shawl did not itch	Therefore the alarm clock did not tick
If the typewriter rattles	then the hail is cold	The hail is cold	Therefore the typewriter rattled
If the bee buzzes	then the faucet is hot	The bee did not buzz	Therefore the faucet is not hot
If the thunder rumbles	then the rag is moist	The thunder rumbled	Therefore the rag is moist

Appendix C.

List 2 of Modal Conditional Reasoning Problems

Appendix C.

List 2 of Modal Conditional Reasoning Problems

Clause1	**Clause 2**	**Premise 2**	**Conclusion**
If the pans clang	then the ship's horn is low-pitched	The pans did not clang	Therefore the ship's horn is not low-pitched
If the boy gurgles	then the music is jarring	The boy gurgled	Therefore the music is jarring
If the autumn leaves rustle	then the trumpet sounds shrill	The trumpet did not sound shrill	Therefore the autumn leaves did not rustle
If the high heels tap	then the lion roars	The lion roared	Therefore the high heels tapped
If the tram grinds	then the alarm clock ticks	The alarm clock did not tick	Therefore the tram did not grind
If the brushwood crackles	then the typewriter rattles	The brushwood did not crackle	Therefore the typewriter did not rattle
If the saxophone blares	then the bee buzzes	The saxophone blared	Therefore the bee buzzed
If the flute is high-pitched	then the thunder rumbles	The thunder rumbled	Therefore the flute is high-pitched
If the mayonnaise is light yellow	then the squirrel is red-brown	The squirrel is red-brown	Therefore the mayonnaise is light yellow
If the hair is short	then the floor is mottled	The floor is not mottled	Therefore the hair is not short
If the wasp is striped	then the orca is black-and-white	The wasp is not striped	Therefore the orca is not black-and-white

Appendix C.

List 2 of Modal Conditional Reasoning Problems (Continued)

Clause1	**Clause 2**	**Premise 2**	**Conclusion**
If the ham is pink	then the car is blue	The ham is pink	Therefore the car is blue
If the jellyfish is translucent	then the walnut is brown	The walnut is not brown	Therefore the jellyfish is not translucent
If the swimming pool is azure blue	then the peppermint is white	The swimming pool is not azure blue	Therefore the peppermint is not white
If the diamond glistens	then the butter is yellowish	The butter is yellowish	Therefore the diamond glistened
If the broccoli is green	then the honey is golden-yellow	The broccoli is green	Therefore the honey is golden-yellow
If the fingers tingle	then the ant tickles	The ant did not tickle	Therefore the fingers did not tingle
If the dress is velvety	then the shoe is tight	The shoe is tight	Therefore the dress is velvety
If the waterfall is cool	then the candy is sticky	The waterfall is not cool	Therefore the candy is not sticky
If the iodine stings	then the toy is soft	The iodine stang	Therefore the toy is soft
If the shawl itches	then the feather tickles	The feather tickled	Therefore the shawl itched
If the hail is cold	then the iron is hot	The hail is cold	Therefore the iron is hot
If the faucet is hot	then the bath water is lukewarm	The bath water is not lukewarm	Therefore the faucet is not hot
If the rag is moist	then the rain is fresh	The rag is not moist	Therefore the rain is not fresh
If the cricket chirps	then the shirt is striped	The cricket did not chirp	Therefore the shirt is not striped

Appendix C.

List 2 of Modal Conditional Reasoning Problems (Continued)

Clause1	Clause 2	Premise 2	Conclusion
If the scooter hums	then the cellar is dark	The cellar is not dark	Therefore the scooter did not hum
If the airplane is loud	then the eggplant is dark purple	The airplane is loud	Therefore the eggplant is dark purple
If the triangle jingles	then the night is dark	The night is dark	Therefore the triangle jingled
If the railroad crossing rings	then the ice cube is transparent	The ice cube is transparent	Therefore the railroad crossing rang
If the alarm beeps	then the chessboard is checkered	The alarm did not beep	Therefore the chessboard is not checkered
If the rooster crows	then the inner tube is black	The inner tube is not black	Therefore the rooster did not crow
If the truck honks	then the bridge is curved	The truck honked	Therefore the bridge is curved
If the cassette tape is black	then the sand is gritty	The sand is gritty	Therefore the cassette tape is black
If the chocolate is dark brown	then the coin is hard	The chocolate is dark brown	Therefore the coin is not hard
If the razorblade is silver	then the cave is chilly	The razorblade is silver	Therefore the cave is chilly
If the leopard is spotted	then the bone is hard	The bone is not hard	Therefore the leopard is not spotted
If the spinach is dark green	then the mosquito bite itches	The spinach is dark green	Therefore the mosquito bite itched
If the water is muddy	then the cotton candy is sticky	The cotton candy is not sticky	Therefore the water is not muddy

Appendix C.

List 2 of Modal Conditional Reasoning Problems (Continued)

Clause1	**Clause 2**	**Premise 2**	**Conclusion**
If the table-top is oval	then the eraser is rough	The eraser is rough	Therefore the table-top is oval
If the tennis ball is yellow	then the bee stings	The tennis ball is not yellow	Therefore the bee did not sting
If the snake hisses	then the marble is rock hard	The snake hissed	Therefore the marble is rock hard
If the station hall is noisy	then the light bulb is very hot	The station hall is not noisy	Therefore the light bulb is not very hot
If the bicycle bell rings	then the teapot is warm	The teapot is not warm	Therefore the bicycle bell did not ring
If the dog barks	then the snowball is cold	The snowball is cold	Therefore the dog barked
If the siren wails	then the sand can grind	The sand cannot grind	Therefore the siren did not wail
If the fly buzzes	then the wound hurts	The wound hurt	Therefore the fly buzzed
If the church organ clangs	then the bed is spongy	The church organ did not clang	Therefore the bed is not spongy
If the doorbell rings	then the toast is warm	The doorbell rang	Therefore the toast is warm

Appendix D.

List of Practice Items

Appendix D.

List of Practice Items

Clause1	**Clause 2**	**Premise 2**	**Conclusion**
If there is a valet	then there is a credit card	There is a valet	Therefore there is a credit card
If the rain is heavy	then it is helpful to carry an umbrella	It is not helpful to carry an umbrella	Therefore it is raining heavily

Appendix E.

List 1 of Non-Modal Conditional Reasoning Problems

Appendix E.

List 1 of Non-Modal Conditional Reasoning Problems

Premise 1	**Premise 2**	**Conclusion**
All Y are Z	All T are Y	Therefore all T are Z
No W are U	All E are W	Therefore no E are U
All R are F	Some Q are R	Therefore some Q are F
No L are O	Some J are L	Therefore some J are not O
All P are B	No A are B	Therefore no A are P
No K are T	All D are T	Therefore no D are K
All X are N	Some S are not N	Therefore some S are not X
No Z are Y	Some Z are Y	Therefore some H are not Z
All H are T	Some H are B	Therefore some B are T
Some U are O	All U are K	Therefore some K are O
No D are W	Some D are X	Therefore some X are not W
Some J are not A	All J are T	Therefore some T are not A

Appendix E.

List 1 of Non-Modal Conditional Reasoning Problems (Continued)

Premise 1	**Premise 2**	**Conclusion**
All N are G	No G are Q	Therefore no Q are N
Some I are C	Some C are L	Therefore some L are I
No R are F	Some F are V	Therefore some V are not R
All C are U	Some S are not C	Therefore no S are U
All Q are K	Some U are Q	Therefore some U are not K
Some X are not R	Some Y are not X	Therefore no Y are R
Some G are not P	No V are G	Therefore no V are P
All I are F	Some D are not I	Therefore some D are not F
No I are K	Some B are I	Therefore some B are K
Some T are Q	All U are T	Therefore some U are Q
No Q are B	No K are Q	Therefore all K are B
All S are L	All M are S	Therefore some M are not L
All G are H	Some E are not G	Therefore some E are H

Appendix E.

List 1 of Non-Modal Conditional Reasoning Problems (Continued)

Premise 1	**Premise 2**	**Conclusion**
No E are X	Some Z are not E	Therefore all Z are X
Some Q are Z	Some F are Q	Therefore all F are Z
All E are X	All B are E	Therefore no B are X
Some W are Y	No S are W	Therefore some S are Y
All T are Y	No A are T	Therefore some A are not Y
Some C are T	Some L are not C	Therefore no L are T
No Y are T	No W are Y	Therefore no W are T
All O are A	Some M are O	Therefore all M are A
Some A are N	All J are A	Therefore no J are N
All X are D	No V are X	Therefore some V are D
All G are H	No V are G	Therefore all V are H
All Z are B	All A are Z	Therefore some A are B

Appendix E.

List 1 of Non-Modal Conditional Reasoning Problems (Continued)

Premise 1	**Premise 2**	**Conclusion**
Some S are not T	All E are S	Therefore no E are D
Some Y are F	All I are Y	Therefore all I are F
Some V are not B	Some Z are not V	Therefore some Z are B
No R are P	No N are R	Therefore some N are P
Some Q are not U	Some I are Q	Therefore no I are U
No M are O	All F are M	Therefore some F are O
No Z are L	Some A are not Z	Therefore some A are L
All O are M	Some P are O	Therefore no P are M
Some O are not E	Some G are O	Therefore some G are E
Some C are J	Some X are C	Therefore some X are J
Some W are not P	No N are W	Therefore some N are P

Appendix F.

List 2 of Non-Modal Conditional Reasoning Problems

Appendix F.

List 2 of Non-Modal Conditional Reasoning Problems

Premise 1	**Premise 2**	**Conclusion**
All Y are Z	All T are Y	Therefore all T are Z
No W are U	All E are W	Therefore no E are U
All R are F	Some Q are R	Therefore some Q are F
No L are O	Some J are L	Therefore some J are not O
All P are B	No A are B	Therefore no A are P
No K are T	All D are T	Therefore no D are K
All X are N	Some S are not N	Therefore some S are not X
No Z are Y	Some Z are Y	Therefore some H are not Z
All H are T	Some H are B	Therefore some B are T
Some U are O	All U are K	Therefore some K are O
No D are W	Some D are X	Therefore some X are not W
Some J are not A	All J are T	Therefore some T are not A

Appendix F.

List 2 of Non-Modal Conditional Reasoning Problems (Continued)

Premise 1	**Premise 2**	**Conclusion**
All N are G	No G are Q	Therefore no Q are N
Some I are C	Some C are L	Therefore some L are I
No R are F	Some F are V	Therefore some V are not R
All C are U	Some S are not C	Therefore no S are U
All Q are K	Some U are Q	Therefore some U are not K
Some X are not R	Some Y are not X	Therefore no Y are R
Some G are not P	No V are G	Therefore no V are P
All I are F	Some D are not I	Therefore some D are not F
No I are K	Some B are I	Therefore some B are K
Some T are Q	All U are T	Therefore some U are Q
No Q are B	No K are Q	Therefore all K are B
All S are L	All M are S	Therefore some M are not L
All G are H	Some E are not G	Therefore some E are H

Appendix F.

List 2 of Non-Modal Conditional Reasoning Problems (Continued)

Premise 1	**Premise 2**	**Conclusion**
No E are X	Some Z are not E	Therefore all Z are X
Some Q are Z	Some F are Q	Therefore all F are Z
All E are X	All B are E	Therefore no B are X
Some W are Y	No S are W	Therefore some S are Y
All T are Y	No A are T	Therefore some A are not Y
Some C are T	Some L are not C	Therefore no L are T
No Y are T	No W are Y	Therefore no W are T
All O are A	Some M are O	Therefore all M are A
Some A are N	All J are A	Therefore no J are N
All X are D	No V are X	Therefore some V are D
All G are H	No V are G	Therefore all V are H
All Z are B	All A are Z	Therefore some A are B

Appendix F.

List 2 of Non-Modal Conditional Reasoning Problems (Continued)

Premise 1	**Premise 2**	**Conclusion**
Some S are not T	All E are S	Therefore no E are D
Some Y are F	All I are Y	Therefore all I are F
Some V are not B	Some Z are not V	Therefore some Z are B
No R are P	No N are R	Therefore some N are P
Some Q are not U	Some I are Q	Therefore no I are U
No M are O	All F are M	Therefore some F are O
No Z are L	Some A are not Z	Therefore some A are L
All O are M	Some P are O	Therefore no P are M
Some O are not E	Some G are O	Therefore some G are E
Some C are J	Some X are C	Therefore some X are J
Some W are not P	No N are W	Therefore some N are P