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Towards Constructing an Integrated Model for the Cognitive System: Revisiting Semantic Networks

Abstract

Integrative approaches try to relate different constructs in different theories and reinterpret them within a common conceptual framework. In this paper, an integrative framework for cognitive constructs is modelled, proposed and evaluated, using the concept of processing levels. Cognitive processing is divided into feature-based, semantic, and conceptual levels, based on the volume of information used to represent a stimulus. To quantitatively evaluate the structure of this model, 47 participants with impaired valance systems were selected from psychological clinics in Mashhad according to the convenience sampling method. The functioning of the participants' cognitive networks was assessed by the Beck Depression Inventory II, the Semantic Distance Task, the Verbal Fluency Test, the Computerized Dot Probe, the Stroop Test, the Implicit Association Test, and the Wisconsin Card Sorting Test. The proposed structural model was formed by using tests scores as predictor variables and levels of processing as mediating variables. The research data were analysed through the PLS Structural Equation Model and the exploratory approach. The best fitted model with a normative fit index of 0.92 confirmed the three-level data clustering hypothesis. Path coefficients between feature-oriented and semantic levels and for semantic and conceptual levels obtained $\Phi = 0.38$ and $\Phi = 0.46$ respectively. In previous studies, interpretations of both the Implicit Association Test and the Verbal Fluency Test were controversial. Using the notion of processing levels, these variations have been reinterpreted.
Keywords: semantic network; structural equation model; cognitive system

1 Introduction

Disorders related to the emotional stimulus processing system, including depression, have the highest global prevalence rate among psychological disorders (World Health Organization, 2017). These disorders cause a lack of pleasure and a severe decrease in motivation in daily life. Nearly 15% of people worldwide has experienced at least one period of major depression. Taking into account the symptoms of chronic depression and mood swings in women caused by premenstrual tension, over 300 million people in the world are struggling with one of this type of disorder (Nateghian et al., 2018). In Iran, psychological disorders account for 14.5% of diseases. After cardiovascular diseases and diabetes, the prevalence of psychiatric disorders is a priority and over 6 million of Iranians suffer from depression (Hakim Shooshtari et al., 2016).

Cognitive science theorists have attempted to describe why and how disorders affect cognitive constructs and the functioning of the mind through theoretical models. Feature integration theory (Treisman & Gelade, 1980) and Posner's theory of attention and working memory, for example, try to explain how CNS chooses which stimuli to be processed. When comparing these fundamental

theories of cognition, it is noticeable there does not exist any systematic relationship between the notions of the main constructs, such as perception, attention, memory, semantic network and executive function. In the attention model, for example, the orientation component causes attention to be drawn to an external or internal stimulus. This component has a similar function to the sensory prioritization process in feature integration theory. Also, the executive control component of the attention model chooses between stimuli (Petersen & Posner, 2012) and is similar to the central executive control component in the working memory theory (Repovš & Baddeley, 2006). An interpretation of different studies that evaluates the common constructs of different models is not possible without an integrated theoretical framework which can provide a conceptual relationship between these constructs. In order to create this theoretical framework, it must be ascertained what the constructs have in common and how they are related. This paper intends to introduce an integrated approach to examining the relationship between cognitive constructs by using the concept of processing levels and determining the position of the semantic network in these levels.

The concept of processing levels is widely used in cognition analysis. For example, in Marr's theory of vision the nervous system first represents the low-level features layer of the stimulus. Afterwards, the conceptual layer is represented, and finally at the third level the semantic layer is represented and the object is recognized (Marr, 1982/2010). At the level of hardware analysis, it has been found that nerve cells in the cerebral cortex are organized on at least six separate levels. Some cells process at a certain level and others, besides processing at one level, have the task of communicating between levels (Gazzaniga, 2008). Different levels of analysis are also responsible for analysing the behaviour of social beings: the level of biological processes, the level of basic psychological processes, the level of individual active behaviour, and finally the level of social interactions. Thus, when a system is composed of different subsystems, interactions within and between processing levels should be examined using the concept of processing levels. From this perspective, stimulus processing by the nervous system can be examined at different levels, from feature processing to concept construction. In this study, the variance in processing "information volume" between feature-oriented, semantic and conceptual levels will be modelled and quantitively investigated.

Processing levels have been used to examine the characteristics of the primary subsystems which comprise the upper level emerging systems (Carey, 2011). When two or more subsystems are interconnected in a common structure, the upper holistic system has several properties which are specific to the higher-level behaviour. If we consider a "single feature" of a stimulus, as the "primary input" into low-level cognition, a set of neurons process this feature and provide a representation of it. To achieve representations of several features, neurons must interact in a common structure to form a larger processing level; the semantic level. At the level of semantic processing, a higher-level representation is built based on primary representations but is still not (linguistically) referable to an external concept. The level of semantic processing provides pre-language materials for external features and events and connects them (Eliasmith, 2013). Finally, with the addition of more detailed features at the conceptual level, each representation can be referred to a specific external concept or common linguistic idea. Propositions, categories, and schemas are placed at the level of linguistic processing, which in this study is generally referred to as the conceptual level.

Figure 1 shows cognitive processing according to the volume of information and elaboration of representations. The first level includes feature-oriented processing, the second is the semantic level (Eliasmith, 2013) and the third level is conceptual processing. At the conceptual level, representations and concepts form larger knowledge structures by forming larger groups of concepts such as propositions and schemas, but the differentiation between them will not be examined in this study. Thus, in this model, the criterion for categorizing the processing levels is the "volume of information" chosen by the nervous system to construct or retrieve the representation of a stimulus under certain conditions. Figure 2 shows how the dimension of processing levels can be categorized using the notion of "Information Volume". At the feature-based level, cognitive

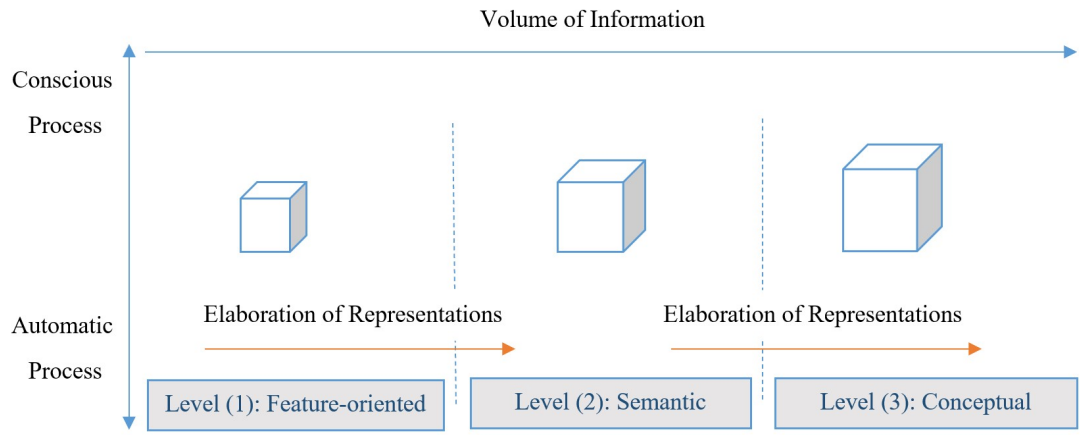


Figure 1. Cognitive processing levels based on information volume: The low level subsystems' neurons elaborate information into more complicated notions which have specific properties, known as emerging properties.

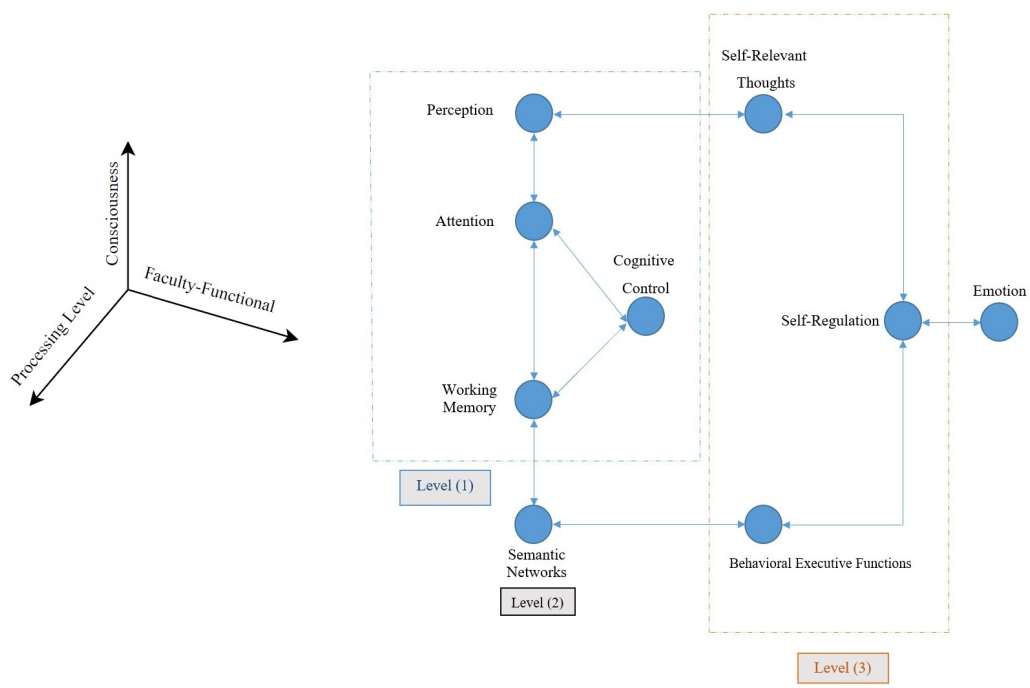


Figure 2. Integrated processing framework and the position of semantic networks in relation to other constructs: every faculty can be studied in 3D dimension of the processing level, physical location and the specific function in the observing process, and the consciousness dimension. Here, the study of the processing level is depicted.

processing focuses on finding specific features of the stimulus and representing them (Bisley & Goldberg, 2010). At the semantic level, the connection between the single-feature representations is connected to other representation based on observation, context, and prior knowledge. In this conceptual framework, the semantic network is introduced as an independent processing level. At the conceptual level (the self-oriented level), concepts, schemas, and propositions are constructed using semantic level representations. Finally, the processing of representations in the cognitive system creates a uniform narrative of external and internal reality in order to be meaningful in relation to prior knowledge (Posner & Rothbart, 1998).

To examine this integrated framework, the effect of mood disorders as a change in the interconnected function of cognitive constructs has been evaluated. Depression is one of the most common mood disorders and there are many studies on its effect on cognition. As a result, the explanatory power of the proposed framework can be well measured. Also, depressive syndromes are often associated with other disorders of emotional stimulus processing, which leads to a wider range of data for the purposes of model evaluation. Two primary goals have been pursued in this research: firstly, to provide and evaluate an integrated framework for cognitive constructs and secondly, to propose an organized position for semantic networks and their function in the cognitive system. In order to evaluate the proposed structural model quantitatively, cognitive test scores were assigned as predictive variables and three levels of cognitive processing, feature-oriented, semantic and conceptual, were considered as mediating variables.

2 Method

The study population was selected from patients of psychological and psychiatric clinics in Mashhad who have impaired processing of emotional stimuli and low mood symptoms. Most of the patients have a moderate income, so any impacts of poverty on their cognitive state could be discounted. Sampling was done by the accessible method. The participants were not controlled for age, education, gender, level of drug use, or comorbidities. In this study, only the effects of emotional stimulus processing disorders as a cognitive state changer has been studied in order to explore the power of the proposed model to reproduce the pattern of relationships between cognitive constructs. The problem of how a disorder affects a specific cognitive function was not within the scope of this study. The proposed processing levels involve faculties which are multidimensional in nature. Providing an adequate number of predictors which correlate together would require a confirmatory study at each level, therefore low values of correlation between predictor variables is a reasonable expectation for the data processing approach. The best SEM method to handle these data types would be Formative PLS-SEM[1] (Hair et al., 2017). In this method, with a statistical power of 80%, minimum R2 of 0.25, statistical significance of 5%, and a maximum 5 predictor paths, a minimum sample size of45 is necessary (Hair et al., 2017). Therefore, considering a 10% drop in participants, a sample size of 50 people was selected, all of whom were under treatment of schema or couple therapy. Some of the participants were taking antidepressants because of a previous diagnosis of depression. None of them had previously undergone neurological surgery.

2.1 Operational Definition of Mediating Constructs

2.1.1 Feature-Oriented Processing Level As figure 3 shows at the Feature-Oriented level, the observed variables of attention, working memory and cognitive control have been selected in order to predict the construct.

Attention: The attention bias of the participant was measured by the Dot Probe Test.

Working Memory: The function of working memory was measured by the Verbal Fluency Test. Interpretation of this test has often been controversial, using it provides an opportunity to reinterpret its results in an integrated processing framework.

[1] Partial least squares structural equation modeling.

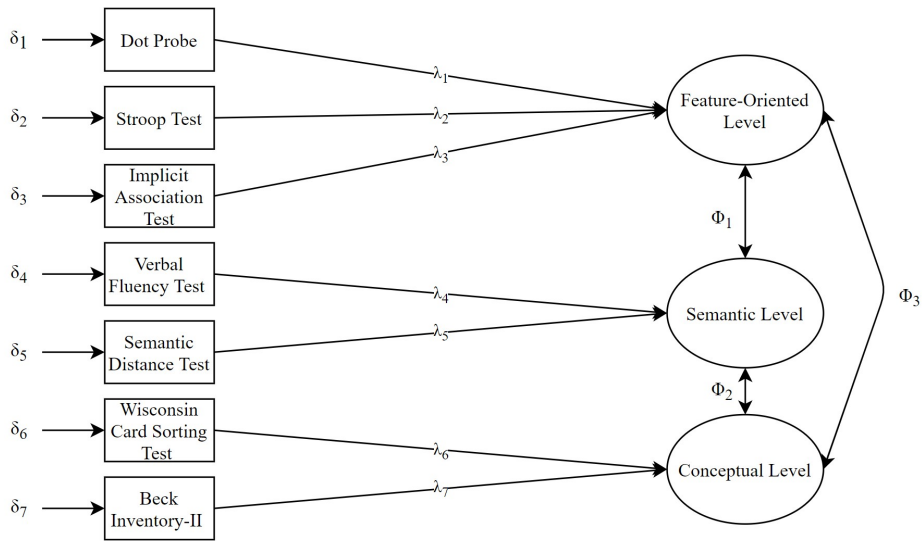


Figure 3. SEM specification for the proposed integrative model.

Cognitive Control: The function of cognitive control was measured by the Stroop Test and with neutral stimulus, due to the fact that it helps to observe construct relations specifically, instead of just the effects of low mood disorders on the function of cognition.

2.1.2 Semantic Processing Level At this level, the observed variables of the Implicit Association Test and Semantic Distance were selected to predict the construct.
Implicit Association Test: The automatic attitude of a person towards a dual concept is known as implicit association. The degree of association between memory elements is measured using the implicit association test for depression.
Semantic Distance: The amount of distance that a person expresses between the concept of self and the concepts of the future, past, joy, happiness, and sadness is measured using the Semantic Distance Task.

2.1.3 Conceptual Processing Level At this level, the observed variables of Depression Symptom Severity and Cognitive Executive Function were selected to predict the construct.
Depression Symptom Severity: Depression symptom severity is measured using the Beck Depression Inventory-II. This test is used to measure at the conceptual level, as it is related to one's thoughts from a self-perspective.
Cognitive Executive Function: It is measured by the Wisconsin Card Sorting Test. This test is related to the propositional level and therefore has been used as a predictor at the conceptual level.

2.2 Materials

2.2.1 Beck Depression Inventory II In the 21-question version of this questionnaire, each question has a score of 0 to 3, and all the questions must be answered (Strauss et al., 2006). The final score of each participant is his/her average score. The internal validity of the questionnaire and the Cronbach coefficient are reported 0.93 and 0.81 respectively. The internal correlation coefficient of the Persian version is 0.81 and the Cronbach's alpha is reported 0.93 (Ghisvandi et al., 2015).

2.2.2 Dot Probe This test is used to assess automatic attention bias (Bradley et al., 1992). In this experiment, a pair of verbal stimuli, one with an unpleasant valance and one with a neutral valance, are shown to the participant on the screen. These verbal stimuli are then removed from the screen, and a red dot appears as the target stimulus on the right or left side of the screen. The difference in the mean reaction rate to the dots appearing on unpleasant side and those appearing on the neutral side is recorded as the participant's score. The validity of Cronbach's alpha test is reported between 0.9 and 0.96. The validity coefficient of the Persian version is reported between 0.78 and 0.92 (Maleki et al., 2013).

2.2.3 Stroop Test This test is designed to measure the number of errors and the reaction time against the interference effect. In this research, a colour 96-word version of the test was used. Participants' scores are obtained from the difference in reaction time to congruent and incongruent stimuli. The reliability of the test in the training and main stages is reported to be 0.1 and 0.9, respectively. The reliability of the Persian version is reported between 0.6 and 0.97 (Hosseini et al., 2016).

2.2.4 Implicit Association Test In this test, a person's attitude (for example, "ugly", "beautiful") is measured towards two different categories (for example, "insects", "birds"). The difference in the reaction time to insects/ ugly, birds/ beautiful and to insects/ beautiful, birds/ ugly is recorded as an implicit association score to the concepts of insects and birds (Greenwald et al., 2003). The reliability and validity of the Persian version is reported between 0.5 and 0.6 and 0.7 to 0.9 respectively (Panahandeh et al., 2014).

2.2.5 Wisconsin Card Sorting Test In this test, the participant is asked to determine which group each card belongs to (Ilonen et al., 2000). After placing several cards correctly, the rule changes and the person must discover the new rule according to the feedback given. In this study, the conceptual level score of each participant is recorded as his/her score. The validity of this test for measuring cognitive deficits is reported to be more than 0.86. Its agreement coefficient reliability is reported 0.83 and the reliability of the Persian version is reported 0.85 (Hosseini et al., 2016).

2.2.6 Semantic Distance Test In this test, the participant imagines him/herself sitting around a circular table at an imaginary party with the concepts of past, future, sorrow and joy. The participant is asked to specify his/her position and each concept. Each person's score is determined by their distance from the concepts (Bartczak & Bokus, 2017). The reliability of this questionnaire using Cronbach's alpha method is 0.65 and the validity of the Persian version is 0.58 (Soltani et al., 2013)

2.3 Research Method

Firstly, the available clinics were selected and then the psychiatrists and psychologists were informed of the requirements of the participants using the research introduction sheet. Participants could not have obvious defects in speech production. They had to be able to learn how to perform computer tests easily, and their response speed would not be impaired by of difficulties in movements and learning. In order to ensure the familiarity of the participants with the tests, a 5-minute practice session was conducted. The stimuli used in the practice tests differed from the stimuli used in the study. Among the volunteers, 50 were selected who had the best computer skills. In the first session, the research steps were explained to the participants and if the person was interested, consent was obtained for the anonymous use of the data. The consent form was

prepared under the requirements of the American Psychological Association (American Psychological Association, 2010). Participants were then asked to answer the Beck Depression Inventory and Semantic Distance Test. In the second session, computer tests were performed. The computer Tests were designed by PSYCHOPY software and performed on a computer device with a 13-inch screen. The observed data were transformed into a 47×8 matrix and analysed in an exploratory approach by Smart-PLS software.

3 Results

The study population consisted of 21 males and 26 females of similar age ($\mu = 34.1$ and $SD = 6.14$). The level of education of the men ($\mu = 16.6$ and $SD = 2.99$) and women ($\mu = 16.7$ and $SD = 1.19$) was similar. According to the Beck questionnaire, 40% of participants had mild disorders, 30% moderate, 17% severe, and 13% had very severe disorders. The results of the descriptive analysis showed that the Stroop Test ($k = +7.45$) and the Implicit Association Test ($k = +3.8$) had the highest skewness among the performed tests.

The correlation state of predictors (Table 1) shows that they are not significantly correlated and the chosen method of PLS-SEM is appropriate for this study.

Table 1. Correlation matrix of predictors.

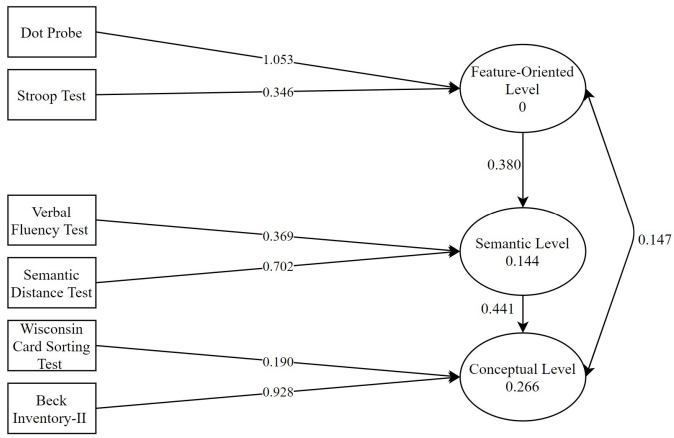
	Severity	SDM	Dot Probe2	Stroop Test	Word Fluency	Implicit Association	Wisconsin Card Sorting
Severity	1						
SDM	0.27	1					
Dot Probe2	0.26	0.29	1				
Stroop Test	−0.02	0.02	−0.32	1			
Word Fluency	−0.31	−0.68	−0.24	−0.03	1		
Implicit Association	0.16	0.10	−0.07	−0.04	−0.00	1	
Wisconsin Card Sorting	−0.34	−0.17	−0.12	0.30	0.22	−0.46	1

The results of the data analysis using the hypothetical model and alternative models (Table 2), shows that the three models had an acceptable fit index. All three models confirmed the triple clustering of the data pattern. Figure 4 shows the structure of these three models. The difference between these three models is in the position of IAT[2] scores as a predictor. Participants in the IAT task must react to stimulus in the shortest possible time to show their functionality at the automated processing level. In the depression version of the IAT, however, the stimuli are completely verbal, and it may require attention to process them consciously. In this study, the highest path coefficient for the IAT is obtained at the semantic level, not the feature-oriented level. While the IAT is often used to measure the relationship between concepts in long-term memory, these results suggest the version of the IAT with verbal stimuli assesses the semantic level.

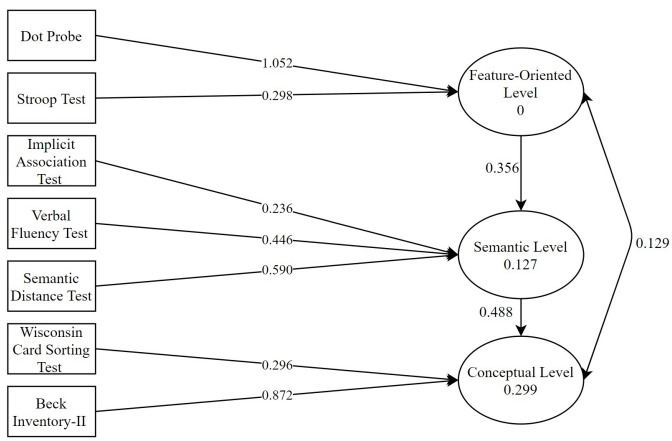
Figure 4 shows that the T-statistic is acceptable for the correlation of mediating between levels 1 to 2 and between levels 2 to 3, for the IAT position of both modes at the semantic or conceptual level. At the semantic level, however, the T-statistic is higher and the P-value is less.

According to the normative fit indices (Table 3), in all three models the assumption of three-level clustering of the data and the relationship between these levels has been confirmed. The high P-value in the results shows that although the T-statistic is sufficient for the validity of these results, a sufficient level of reliability needed to draw certain conclusions is not obtained, because

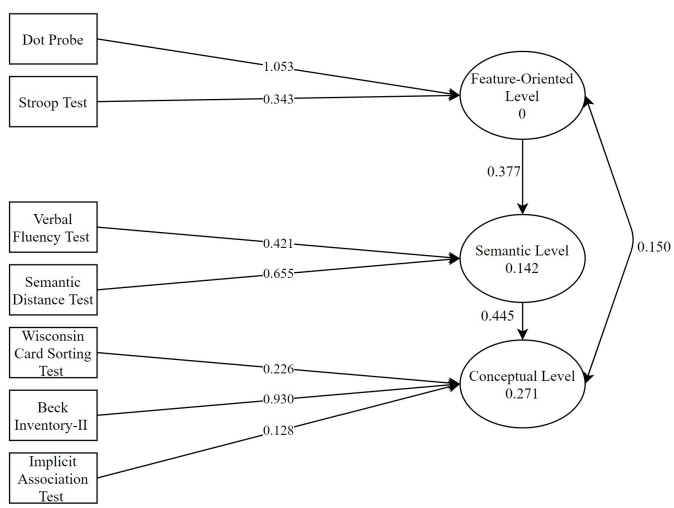
[2] Implicit Association Test



a.



b.



c.

Figure 4. SEM specification for the proposed model.
a. Without IAT considered in model. b. IAT is considered to be related to semantic level. c. IAT is assumed to be involved in conceptual level of processing.

Table 2. Comparison of path coefficient in three models with the highest fit index.

Path	Model Alternative	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (|O/STDEV|)	P Values
		0.15	0.18	0.21	0.69	0.49
	Without IAT	0.38	0.17	0.40	0.95	0.34
		0.44	0.16	0.46	0.95	0.34
Feature Oriented → Conceptual level		0.13	0.17	0.22	0.58	0.56
Feature Oriented → Semantic level	IAT in 2nd stage	0.36	0.02	0.43	0.82	0.41
Semantic level → Conceptual level		0.49	−0.04	0.54	0.91	0.36
		0.15	0.15	0.23	0.64	0.52
	IAT in 3rd stage	0.38	0.26	0.35	1.07	0.29
		0.45	0.35	0.39	1.13	0.26

of the multidimensionality of the proposed constructs. It can also be seen that the model fit index was higher without the IAT score mode of assessment, due to the dispersion of IAT scores.

4 Discussion

According to the model fit indices, the hypothesis of triple clustering of the observed data ("feature-oriented", "semantic" and "conceptual") is confirmed. The results of the T-test show that the Stroop, Semantic Distance and Beck depression Inventory-II scores have the highest factor loads. One category is formed based on the Dot Probe and Stroop scores, which correspond to the feature-oriented level. The other group is based on the test score of the Semantic Distance Task and the Verbal Fluency scores, which are equivalent to the level of semantic processing. The third group is formed by the Beck Depression Inventory-II, Wisconsin and IAT with self-related stimuli scores, which represent the conceptual level. These findings are consistent with the first hypothesis of the study. The goodness-of-fit index is 0.92. The accuracy of the path coefficients between the three mediating variables was confirmed by T-test, but due to the high P-value, more data are needed to have a more certain conclusion.

The second hypothesis of the research is that the relationship pattern within the integrated framework between the scores of cognitive tests, mediating variables and semantic level as an independent construct will be confirmed. The VIF-statistics are higher than 1 for all variables, which indicates a good reproduction of the data pattern. However, a high Chi-Square value indicates low certainty in the results, along with high P-Values. This may be solved with more data, but a more fundamental step in subsequent studies is to select a larger number of predictor variables from each mediating construct to reduce the residual prediction error at each level. Also, in this study the variable of the Semantic Distance Task was highly correlated with the semantic level. This result is in accordance with a previous study, which proposes SDT[3] to measure the distance between self and the notions of future and past. The informative value of this task to assess an individual's perspective without any interview is significant (Bartczak & Bokus, 2017).

[3] Semantic Distance Test

Table 3. Comparison of model evaluation criteria in three models with the highest fit index.

Criteria	Variation	Without IAT	IAT in 2nd stage	IAT in 3rd stage
R Square Adjusted	Feature Oriented	—		—
	Semantic level	0.12	0.10	0.12
	Conceptual level	0.23	0.26	0.23
rho_A[4]	Feature Oriented	1.00	1.00	1.00
	Semantic level	1.00	1.00	1.00
	Conceptual level	1.00	1.00	1.00
Collinearity statistics (VIF[6])	Dot Probe	1.11	1.11	1.11
	IAT[5]	—	1.05	1.09
	SDM	2.04	2.12	2.04
	Severity	1.10	1.10	1.10
	Stroop Test	1.11	1.10	1.11
	Wisconsin	1.10	1.10	1.16
	Word Fluency	2.04	2.10	2.04
	Feature Oriented → Conceptual Level	1.17	1.15	1.17
	Feature Oriented → Semantic level	1.00	1.00	1.00
	Semantic level → Conceptual Level	1.17	1.15	1.17
Estimated Model Fit Indexes[9]	SRMR[7]	0.04	0.06	0.04
	d_ULS[8]	0.04	0.09	0.05
	d_G[10]	0.01	0.03	0.03
	Chi-Square	2.85	6.01	5.12
	NFI[11]	0.95	0.91	0.92

According to Table 1, when the participant responds at a higher speed the IAT can assess the implicit association of representations at the semantic level. However, when the participant spends more time deciding on self-characteristics more consciously, the propositional algorithm activates. It seems that most participants used the propositional algorithm and ignored clear instructions to answer IAT test as quickly as possible. Various studies have been performed on the validity of the IAT. It has been reported that the motivation of participants or their commitment to answering the questions as quickly as possible may influence the results (Meissner et al., 2019). Therefore, referring to the proposed framework, it is recommended to conduct a test twice with each participant: one test with stimuli at the pre-lingual and feature-oriented level, and a second test with stimuli at the semantic level. In this way, the difference between automatic and non-automatic processing can be compared and may tell us more about the underlying mechanism of the implicit activation of notions.

[4] rho_A reliability coefficient.
[5] Implicit Association Test.
[6] Variance Inflation Factor.
[7] Standardized Root Mean Square Residual.
[8] The squared Euclidean distance.
[9] d_ULS and d_G show two different measure of discrepancy.
[10] The geodesic distance.
[11] Normed Fit Index.

The consciousness spectrum is often neglected when interpreting the results of psychological tests. In this study, the Dot Probe assesses the automatic processing of attention to a visual verbal stimuli, and the Stroop test measures more conscious attention to similar stimuli. Both these tests measure at the feature-oriented level and display a good relationship with feature-based constructs, but they are not correlated. Also, the Dot Probe scores show a much higher factor load with the semantic networks construct. Differences in the consciousness spectrum or the different emotional valence of the stimuli in these two tests may be the reason. Nevertheless, these results emphasize that when interpreting the results of a test, the consciousness spectrum is important, in addition to the level of processing.

4.1 Limitations

The scope of this research is to emphasize the importance of processing levels for finding an integrated cognitive framework. The limitation of this research stems from balancing the complexity of the subject and the feasibility of the research design. In order to measure the validity of these results, their replication with more data from different aspects of cognitive constructs at all three levels is necessary. Due to the lack of control over the use of drugs, the treatment of participants, and comorbid disorders, the results cannot indicate the effect of depression on cognition.

4.2 Suggestions

The results of this research can be used to formulate the problem of how to build an integrated cognitive model. In the future, we may ask what the most important tests for analysing the relationship between cognitive constructs at each level are. These tests should specifically assess the feature-oriented, semantic, and conceptual levels from a variety of perspectives, and two tests should be selected at the automated and conscious levels. The relationship between these tests and each level should be examined by confirmatory factor analysis. After constructing a certain model for each level, it is possible to analyse the paths between processing levels. Also, the relationship between two automated and conscious modes in each level could be studied systematically so as to clarify the role of the consciousness spectrum in the analysis of cognitive tests. Creating an integrated model will help in the comprehensive interpretation of studies based on different theories and to establish a more organized relationship between cognitive constructs.

4.3 Data Availability Statement

The datasets generated for this study can be accessed by emailing A. Ehsani armin.ehsani@mail.um.ac.ir.

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