Semantic competency as a marker of clinical reasoning performance [version 1; peer review: awaiting peer review]

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Abstract

Background: This study sought to explore the relationship between semantic competence (or dyscompetence) displayed during “think-alouds” performed by resident and attending physicians and clinical reasoning performance.

Methods: Internal medicine resident physicians and practicing internists participated in think-alouds performed after watching videos of typical presentations of common diseases in internal medicine. The think-alouds were evaluated for the presence of semantic competence and dyscompetence and these results were correlated with clinical reasoning performance.

Results: We found that the length of think-aloud was negatively correlated with clinical reasoning performance. Beyond this finding, however, we did not find any other significant correlations between semantic competence or dyscompetence and clinical reasoning performance.

Conclusions: While this study did not produce the previously hypothesized findings of correlation between semantic competence and clinical reasoning performance, we discuss the possible implications and areas of future study regarding the relationship between semantic competency and clinical reasoning performance.

Keywords

Semantic competence, clinical reasoning, expert performance, cognitive load theory
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Introduction

At the heart of most health professionals' responsibilities is the task of clinical reasoning, in which the health professional processes clinical and contextual (e.g., situational) information to make patient care decisions (Durning et al., 2013). Clinical reasoning thus encompasses all of the cognitive steps up to and including the arrival at a diagnosis or management plan for a patient (Durning et al., 2010). Clinical reasoning is one of the central pillars of physician performance in any specialty and therefore warrants considerable focus in health care. Indeed, perhaps more than any other subject, medical education should strive to produce clinical reasoning expert performance (Durning et al., 2013).

Expert performance in a field is believed to be achieved through deliberate practice, in which the individual dedicates deliberate (effortful) practice not just to performing the task but to performing the task with a mindful dedication toward improving their performance in that domain, which requires reflection on both the outcomes and the underlying processes (Ericsson et al., 1993). Achieving expert performance in clinical reasoning arguably requires deliberate practice, and deliberate practice requires that we find ways to assess not just the outcomes of clinical reasoning (i.e., diagnosis and management plans), but also underlying clinical reasoning processes that are occurring within the trainee’s mind (i.e., steps proximal to the diagnosis and/or management) (Durning et al., 2013). Given the very nature of clinical reasoning as a thought-based endeavor, it is difficult to design authentic, feasible assessment methods with good reliability and validity evidence for evaluating clinical reasoning processes (Askew et al., 2012; Cambron-Goulet et al., 2019; Daniel et al., 2019 and Lessing et al., 2020). Because of this difficulty in assessment, it is also therefore difficult to design educational experiences to support expert performance in clinical reasoning.

Developing methods to assess clinical reasoning processes requires a detailed understanding of physician thought. Contemporary thinking emphasizes knowledge organization as playing a central role in clinical reasoning. Knowledge organization refers to how information is believed to be intertwined (or interdigitated) in memory so that it can be rapidly, effectively, and efficiently recalled and used (Custers et al., 1996). One of the potential windows into one’s knowledge organization may be through the words clinicians use when communicating their thought process; from this arises the concept of semantic competence in clinical reasoning. Semantic competence describes the use of abstract, often binary, terms that are used to describe a patient’s presentation among physicians (Bordage, 1994; Bordage et al., 1997). For example, recognizing that a patient’s presentation of six hours of wrist swelling, warmth, and tenderness is “acute, monoarticular, arthritis” is an example of semantic competence. Semantic competence is believed to represent an early transformation of knowledge organization and thus a potential target for assessing clinical reasoning processes (ten Cate & Durning, 2018).

Prior research by Bordage and colleagues has pointed to semantic competence during case presentations as a potential marker of more successful clinical reasoning (meaning that the subject is more likely to arrive at the correct diagnoses in their differential if they manifest semantic competence) (Bordage, 1994; Chang et al., 1998). However, additional research into correlating semantic competence with clinical reasoning performance has not shown a clear connection, which may in part be due to the challenges with identifying and achieving consensus with labeling semantic competence as well as a limited number of clinical cases included in the study (see Bordage, 2007, for a discussion of the challenges of studying semantic competence).

Whether or not semantic competence is associated with superior clinical reasoning performance, it is crucial to understand the theoretical underpinning of any possible connection. In other words, if clinicians exhibiting higher degrees of semantic competence have superior clinical reasoning performance, why is that? In order to make this leap, we must first understand the closely related idea of illness script theory, which holds that information about a specific disease is stored in long term memory with varying degrees of accessibility and inter-connectedness based on that clinician’s experiences (e.g., a clinician who has seen many patients with a specific disease in many different contexts and presentations may have a better-developed illness script for that disease) (Custers et al., 1996). Novice clinicians may have a more difficult time accessing the illness scripts in their long term memory due to less development and/or interconnectedness, if such scripts exist at all; this may hold particularly for those who have either not seen a particular illness or who have not yet established well-organized knowledge on the topic in their long term memory (ten Cate & Durning, 2018). Well-developed illness scripts may be associated with arriving at the correct diagnosis more quickly as well as producing superior management plans (Custers et al., 1996 and Monajemi et al., 2012). There therefore exists the intriguing possibility that semantic competence may serve as a window into the knowledge organization within a clinician’s brain, and therefore serve as a marker of the underlying scaffolding necessary to establish expert clinical reasoning performance.

A physician who is able to adeptly express their thoughts about the patient’s verbal contribution in a semantically competent manner is likely demonstrating superior knowledge organization. By contrast, physicians with significant prior experience in an area (e.g., medical resident or attending seeing a common disease presentation in their field) who fail to make this articulation, or who do so in a more delayed or even erroneous manner (e.g. semantic dyscompetence), may be demonstrating poor knowledge organization. For example, if a physician is able to successfully express the patient’s complaint of “being constantly thirsty and having to urinate a lot” as “polydipsia and polyuria,” it is likely that this individual has activated a more organized knowledge network within their long-term memory.

Beyond semantic competence itself, automaticity is also believed to be an important consideration for evaluating the relationship between the words that a physician uses and their underlying mental processes. Dual process theory holds that
two distinct thought processes are occurring within the brain, one of which is fast (or system 1) thinking, which is quick, largely subconscious and low effort, and typically used with more knowledge organization (e.g. pattern recognition); and the other of which is slow (or system 2) thinking, which is more deliberate and higher effort. (Croskerry, 2009; ten Cate & Durning, 2018). Indeed, physicians displaying more system 1 thinking may perform superiorly in clinical reasoning tasks because they have freed up needed working memory space to learn and perform in the situation. A greater degree of system 1 thinking may manifest through the more automatic expression of thoughts (i.e. semantic competency), but the degree of system 1 thinking may also be reflected in the amount of time or number of words they use during their thinking process.

In this study we sought to explore the relationship between semantic competence (and dyscompetence) and clinical reasoning performance. We hypothesized that semantic competence or dyscompetence was a marker of underlying knowledge organization or disorganization respectively, and ultimately would have an impact on clinical reasoning performance. We believed that use of semantic competence would be linked to superior clinical reasoning performance, suspecting that it would be a marker of superior knowledge organization.

More specifically, we made the following hypotheses:

1. The number of dyscompentencies recorded during the think-aloud would be associated with poorer performance on the post-encounter form (PEF).
2. A physician with no semantic dyscompetencies would perform better on a measure of clinical reasoning performance (the PEF).
3. The presence of dyscompetencies would indicate poorer knowledge organization, leading to poorer performance on this PEF.
4. In those physicians who do not display semantic dyscompetence, the number of instances of semantic competence would be associated with higher performance on the PEF.
5. As a marker of knowledge organization and dual process theory, fewer words used by a physician would be associated with superior clinical reasoning performance.

Methods

Ethics statement
This study was approved by the Uniformed Services University Institutional Review Board, the protocol number for this JPC study is MED-83-3824. Written informed consent of participants was obtained as part of the study.

Study population and setting
As part of a larger study conducted at the Uniformed Services University of the Health Sciences (USU), Walter Reed National Military Medical Center (WRNMMC), and Naval Medical Center San Diego (NMCSD) exploring clinical reasoning, a convenience sample (due to the study time demands and institutional requirements of volunteers only) of 41 resident and attending physicians in internal medicine was recruited from the Uniformed Services University of the Health Sciences, Walter Reed National Military Medical Center, and Naval Medical Center San Diego. Each participant completed two cases each, producing a total of 82 transcripts for analysis. For every physician, one case was a patient presenting with new onset diabetes mellitus and the other presenting with unstable angina. For more details on study design, see both papers from Konopasky and colleagues published in 2020 (Konopasky et al., 2020a; Konopasky et al., 2020b).

Data collection
After obtaining informed consent, the participants were quasi-randomized (randomization was based on participant schedules) into one of three groups based on their geographic and schedule availability. The participants watched videotapes of a physician interacting with a patient and then completed a computerized free-text PEF (Extended data (Berge, 2021)), which asked the participants to provide: 1) what additional history they would obtain from the patient, 2) what additional physical exam findings they would look for, 3) complete problem list, 4) differential diagnosis, 5) leading diagnosis with supporting data, and 6) a treatment plan. Participants had up to 30 minutes to complete the PEF (which was found to be ample time in prior trials). During the think aloud, the participant was accompanied only by the study personnel, who did not intervene except to provide guidance on the think aloud and PEF completion. This PEF has reliability and validity evidence for assessing clinical reasoning (Durning et al., 2011). Items were scored as in prior research where reliability and validity evidence for this instrument were established (Durning et al., 2012 and McBee et al., 2017); each free-text response (most participants gave multiple responses for each question) was scored as correct (2 points), partially correct (1 point), or incorrect (0 points) based on a predetermined scoring key developed by a panel of board certified internists (Durning et al., 2012 and McBee et al., 2017), with reliability between kappa = 0.82 and kappa = 0.93 in measure development. Participants were only able to give a single response for the leading diagnosis, but gave multiple responses for the other items.

Immediately following PEF completion, the participants completed a think-aloud protocol (Boren & Ramey, 2000) as they rewatched the video. The “think-aloud” protocol has been shown in other studies to be an effective way to evaluate clinical reasoning (Burbach et al., 2015; Durning et al., 2012; Funkesson et al., 2007). In the think-aloud procedure the participant verbalizes their thinking as they complete a task with a clear beginning and an end. If the participant does not speak for more than five seconds, they are asked to “think-aloud.” The think-alouds were transcribed verbatim for analysis.

Data measurement
In order to assess clinical reasoning performance, we used an abbreviated PEF score, including only the outcome-related items: the questions asking for differential diagnosis, leading
To assess semantic competence and dyscompetence, a team of coders consisting of one attending physician (study lead), one resident physician, and two medical students reviewed the think-aloud transcripts to identify utterances of semantic competence and dyscompetence. Next, this team of coders collaboratively identified and agreed on a scoring rubric that was also reviewed and discussed with the entire study team (which included two additional attending physicians), including several sessions collaboratively reviewing transcripts until complete consensus was reached. Our coding rules are shown in Table 1 below.

The scoring rubric provided criteria to standardize scoring for semantic competence and dyscompetence, which has been described as a limitation in prior studies (Bordage et al., 1997). Semantic competence was coded whenever the most appropriate clinical terminology was used by the participant during their think-aloud. Dyscompetence was coded whenever the participant used terminology to describe clinical findings, symptoms, or diagnoses that were not considered the most clinically-appropriate terminology, as discussed above.

Data analysis
After all of the transcripts were coded (n = 82), the total number of instances of semantic competence and dyscompetence were recorded for each transcript. Total word count of each think-aloud was also recorded.

Descriptive analysis was performed (using IBM® SPSS® version 25) on all variables to understand the patterns of competence and dyscompetence. To address our hypotheses, we ran correlational analyses to evaluate the relationship between word count, the various coded totals of semantic competence, semantic dyscompetence, and clinical reasoning performance, measured by the participant’s score on the PEF.

<table>
<thead>
<tr>
<th>Table 1. Coding rules.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Competency rules</strong></td>
</tr>
<tr>
<td>1. Semantic competence was coded on the lexical level (i.e., can have more than one semantic competence code within a sentence).</td>
</tr>
<tr>
<td>2. In order to be considered an instance of semantic competence, an utterance must be the most appropriate medical term used in an appropriate clinical context. Specific examples include:</td>
</tr>
<tr>
<td>a. Fatigue (instead of tired/tiredness)</td>
</tr>
<tr>
<td>b. Exertional (instead of “when doing things” or “with activity”)</td>
</tr>
<tr>
<td>3. The appropriate term for a disease process must be used to be considered semantic competence:</td>
</tr>
<tr>
<td>a. “Gastroesophageal reflux disease” or “GERD” would be considered competence. “Reflux” or “heartburn” would be considered dyscompetent.</td>
</tr>
<tr>
<td>4. All appropriately-used descriptors (e.g. acute vs chronic) for signs/symptoms/findings were coded separately as semantic competence utterances. For example: “acute progressive dyspnea” would be coded as three separate instances of semantic competency.</td>
</tr>
<tr>
<td>5. Semantic competence was also coded if used properly in the negative sense (e.g., “The patient is not tachycardic”).</td>
</tr>
<tr>
<td><strong>Dyscompetency rules</strong></td>
</tr>
<tr>
<td>6. Semantic dyscompetence was coded when the participant used lay terminology when more appropriate medical terminology existed (e.g. “the patient is drinking a lot” in lieu of “polydipsia”).</td>
</tr>
<tr>
<td>7. Dyscompetence was also specifically documented when the participant used semantically competent language but subsequently used the analogous semantically dyscompetent terminology (e.g. “the patient has polyuria. They are peeing a lot.”)</td>
</tr>
<tr>
<td><strong>Exclusion rule</strong></td>
</tr>
<tr>
<td>8. Anything that was repeated (i.e., parroting patient’s words) without demonstrating a transformation was not included in analysis (e.g., if the participant used lay terminology, but they were repeating the words from the patient in the video, such as “he says he’s really thirsty,” this was not coded).</td>
</tr>
</tbody>
</table>
Results
There were 41 participants in the study, each of whom reviewed two cases and participated in two think-aloud sessions, resulting in a total of 82 transcripts. The demographics of the participants are detailed in Table 2 below.

The coders evaluated the transcripts for instances of semantic competence or dyscompetence as defined by the rules in Table 1. Descriptive statistics of this evaluation are listed in Table 3.

In an effort to evaluate our hypotheses that quantity of speech and the degree of semantic competence and dyscompetence would be associated with clinical reasoning performance, we ran Pearson correlations \((n = 82)\) between PEF score and 1) word count, 2) total competencies, 3) total dyscompetencies, and 3) the total dyscompetencies (with two-tailed significance), as shown in Table 4.

The main finding was a statistically significant but small negative correlation between think-aloud word count and the participant’s clinical reasoning performance \((p = 0.008)\). A small and weak negative correlation was also seen between the total competency count and the clinical reasoning performance, which is thought to be related to the small/weak positive correlation that was seen between word count and both competencies and dyscompetencies (in other words, participants who spoke more, used both more competencies and dyscompetencies).

In order to evaluate our hypothesis that presence of dyscompetencies may indicate poorer knowledge organization, a comparison of mean PEF score was performed between those with zero dyscompetencies \((n = 26)\) and those with greater than zero dyscompetencies \((n = 56)\), which yielded no statistically significant difference (see Table 5, \(p = 0.242)\)

### Table 2. Demographics of study participants.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Average</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average age</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>Average years of practice (since medical school graduation)</td>
<td>7.2</td>
<td></td>
</tr>
<tr>
<td>Percent female</td>
<td>27%</td>
<td></td>
</tr>
</tbody>
</table>

### Table 3. Descriptive statistics on think-aloud coding.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Average (standard deviation)</th>
<th>Range (minimum-maximum)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abbreviated PEF score</td>
<td>2.00 (0.525)</td>
<td>0.67-2.76</td>
</tr>
<tr>
<td>Word count</td>
<td>648 (419)</td>
<td>190-2094</td>
</tr>
<tr>
<td>Competencies: Total</td>
<td>11.1 (5.33)</td>
<td>1-30</td>
</tr>
<tr>
<td>Dyscompetencies: Total</td>
<td>1.26 (1.39)</td>
<td>0-7</td>
</tr>
</tbody>
</table>

PEF = post-encounter form.

### Table 4. Correlations.

<table>
<thead>
<tr>
<th>Variable</th>
<th>M</th>
<th>SD</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Abbreviated PEF score</td>
<td>2.00</td>
<td>.525</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Word count</td>
<td>648</td>
<td>419</td>
<td>-.292**</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Competencies: Total</td>
<td>11.1</td>
<td>5.33</td>
<td>-.221*</td>
<td>.274*</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>4. Dyscompetencies: Total</td>
<td>1.26</td>
<td>1.39</td>
<td>.029</td>
<td>.224*</td>
<td>.036</td>
<td>-</td>
</tr>
</tbody>
</table>

*p < 0.05. **p < 0.01.

PEF = post-encounter form.
To evaluate if, among those who did not display semantic dyscompetence, the degree of semantic competence was associated with superior clinical reasoning performance, we ran a Pearson correlation within this cohort \((n = 26)\) between abbreviated PEF score and word count and total competencies (see Table 6). No statistically significant relationships were found.

**Discussion**

In order to assess the potential link between semantic competence and clinical reasoning performance, we evaluated the transcripts of think-alouds performed by physicians after watching standardized clinical case videos for semantic competence/dyscompetence. Using a post-encounter form with reliability and validity evidence, we attempted to correlate this semantic competence or dyscompetence with clinical reasoning outcomes. Based on illness script and dual process theory, we sought to explore the relationship between semantic competence, semantic dyscompetence, and clinical reasoning performance, forming several hypotheses around how these markers of knowledge organization (clinical reasoning process measures) would be related to clinical reasoning performance (outcomes) (Bordage, 1994; Bordage et al., 1997; Bordage, 2007; ten Cate & Durning, 2018).

First, we hypothesized that both the presence (e.g., making an utterance) and the degree (e.g., number of such utterances) of semantic dyscompetence would be associated with poorer clinical reasoning performance. This was not demonstrated in our results. This may have reflected the success of the think-aloud process whereby a participant may state what comes to mind without analyzing their thinking, or possibly that participants interpreted the think-aloud prompt as directing them to use layman’s terms, since the researcher asking the questions was not a physician. A future study could explore more formal presentations where the participant would be expected to prepare their presentation. The presence of semantic dyscompetence in this setting may be a more sensitive marker of potential knowledge disorganization. In other words, the resident who says “peeing a lot” in lieu of “polyuria” during a patient presentation on rounds may be demonstrating a different phenomenon than the physician who states “peeing a lot” during a think-aloud exercise.

Our other hypothesis from illness script theory regarding the relationship between semantic competence and clinical reasoning performance was also not confirmed. As was the case above, the effect of the think-aloud protocol on participant thinking was likely at work as in semantic dyscompetence. Additionally, the cases that were used in this study were deemed to be straightforward presentations for the experience level of the physicians participating in the study. Thus, for both semantic competencies and dyscompetencies, these relatively less complex cases may not have been sensitive of superior or poor

<table>
<thead>
<tr>
<th>Groupings:</th>
<th>N</th>
<th>Mean abbreviated PEF</th>
<th>Sth dev</th>
<th>Sth. error mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dyscompetencies &gt; 0</td>
<td>56</td>
<td>2.07</td>
<td>.473</td>
<td>.063</td>
</tr>
<tr>
<td>Dyscompetencies = 0</td>
<td>26</td>
<td>1.85</td>
<td>.608</td>
<td>.119</td>
</tr>
</tbody>
</table>

PEF = post-encounter form

<table>
<thead>
<tr>
<th>Variable</th>
<th>M</th>
<th>SD</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Abbreviated PEF score</td>
<td>1.91</td>
<td>.501</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2. Word count</td>
<td>663</td>
<td>463</td>
<td>.170</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3. Competencies: Total</td>
<td>10.6</td>
<td>5.53</td>
<td>.084</td>
<td>.129</td>
<td>-</td>
</tr>
</tbody>
</table>

*p < 0.05; **p < 0.01.

PEF = post-encounter form
clinical reasoning performance. Future work with more complex cases could reveal a relationship between semantic competencies and dyscompetencies and clinical reasoning performance.

Finally, we also hypothesized that a longer word count would be associated with poorer clinical reasoning performance, and this was verified by our data, which demonstrated a negative correlation between word count and abbreviated PEF score. This is theoretically supported by dual process theory, in that physicians who have less well-developed illness scripts may have “meandered” more in their think-alouds, whereas users with more well-developed scripts may have been more succinct and accurate (Croskerry, 2009; ten Cate & Durning, 2018).

Our study had several limitations. We only gave participants two clinical cases each and while the study contained a moderate number of participants for such a study, the findings may have been different with a larger sample. Also, while our PEF has reliability and validity evidence in this context, it is just one measure of clinical reasoning outcomes.

While our study did not confirm many of our hypotheses, it did demonstrate a slight negative correlation between think-aloud length and clinical reasoning performance. We believe that there is still potential educational value in looking into the link between semantic competence, as a marker of knowledge organization, and clinical reasoning performance. Medical and other health professional educators need ways to assess clinical reasoning processes as well as outcomes to enhance patient care. As we strive to promote expert performance in clinical reasoning amongst our trainees, we need to continue to seek markers of the clinical reasoning process and underlying knowledge organization. Despite the largely negative results of our study, there is still a strong theoretical framework for further study of the link between semantic competence, knowledge organization, and clinical reasoning.

Conclusion
We explored the association between a proxy of knowledge organization (semantic competencies and dyscompetencies) and clinical reasoning performance. The length of the think-aloud was negatively correlated with clinical reasoning performance, supporting dual process theory; however, the remainder of our hypotheses about the relationship between semantic competence/dyscompetence and clinical reasoning performance were not supported. Semantic competence, however, may yet be a potentially useful marker for knowledge organization, despite the lack of statistically significant results in our analysis. This study prompts many follow-up questions, most specifically whether the nature of semantic competence/dyscompetence would change in the setting of formal case presentations or work rounds as opposed to the think-aloud format that we evaluated.

Data availability
Underlying data

This project contains the following underlying data:
- Response Spreadsheet

Extended data

This project contains the following extended data:
- PEF

Data are available under the terms of the Creative Commons Zero “No rights reserved” data waiver (CC0 1.0 Public domain dedication).

References

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