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Using the OASES-A to illustrate how network analysis can be applied to understand the experience of stuttering

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Purpose: Network science uses mathematical and computational techniques to examine how individual entities in a system, represented by nodes, interact, as represented by connections between nodes. This approach has been used by Cramer et al. (2010) to make "symptom networks" to examine various psychological disorders. In the present analysis we examined a network created from the items in the Overall Assessment of the Speaker's Experience of Stuttering-Adult (OASES-A), a commonly used measure for evaluating adverse impact in the lives of people who stutter.
Method: The items of the OASES-A were represented as nodes in the network. Connections between nodes were placed if responses to those two items in the OASES-A had a correlation coefficient greater than ± 0.5. Several network analyses revealed which nodes were "important" in the network.
Results: Several centrally located nodes and "key players" in the network were identified. A community detection analysis found groupings of nodes that differed slightly from the subheadings of the OASES-A.
Conclusions: Centrally located nodes and "key players" in the network may help clinicians prioritize treatment. The different community structure found for people who stutter suggests that the way people who stutter view stuttering may differ from the way that scientists and clinicians view stuttering. Finally, the present analyses illustrate how the network approach might be applied to other speech, language, and hearing disorders to better understand how those disorders are experienced and to provide insights for their treatment.

1. Introduction

1.1. Network science

Network science refers to an emerging discipline that uses mathematical and computational techniques developed in mathematics, sociology, physics, computer science, and other fields to study complex systems. *Nodes* are used to represent

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an individual entity in the system, and *connections* are placed between nodes that are related in some way, forming a web-like structure, or *network*, of the entire system. For example, to study a social system, a node would represent each person in that system, and connections might be placed between people who are friends with each other.

The structure of the network that emerges influences the dynamics of that system. That is, a process may operate very efficiently in a network that is structured one way, but if the network is structured in a slightly different way the same process may become less efficient. For instance, the topology or structure of social networks affects the way information spreads within the network (*i.e*., the dynamics of the system; Strogatz, 2001). A social network could be structured in a way that allows information to be spread rapidly among people (*i.e.,* a more efficient process), or it could be structured in a way where it takes a long time for information to be transmitted (*i.e.,* a less efficient process).

The network approach has been used to examine economical, biological, social, and technological systems (Barabási, 2009), as well as the cognitive systems associated with language processing (*e.g*., Vitevitch & Castro, 2015; Vitevitch, 2008). Instead of looking at a social system containing people connected by friendship ties, Vitevitch (2008) examined the mental lexicon—that portion of memory that stores information about the words a speaker knows—using nodes to represent word-forms and connections between words that were phonologically similar to each other. In experiments using a variety of psycholinguistic tasks, certain aspects of the structure of the network that emerged were shown to influence the production of spoken words (Chan & Vitevitch, 2010), the recognition of spoken words (Siew & Vitevitch, 2016), the acquisition of novel words (Goldstein & Vitevitch, 2014), and how speakers recover when lexical retrieval fails (Vitevitch, Chan, & Goldstein, 2014).

The network approach has also been used to examine how psychological disorders such as *major depressive disorder* or *generalized anxiety disorder* might arise from the relationship found among various psychological and behavioral symptoms (Cramer, Waldorp, van der Maas, & Borsboom, 2010). In these "symptom networks," the psychological and behavioral symptoms that are used in the *Diagnostic and Statistical Manual of Mental Disorders* (DSM) to define various disorders are represented as nodes, and connections are placed between symptoms that tend to co-occur (for an application of network science to bulimic disorders see Forbush, Siew, & Vitevitch, 2016).

From such analyses one can find symptoms that are unique to major depressive disorder and to generalized anxiety disorder, as well as symptoms that act as a "bridge" to connect symptom nodes that are unique to the two disorders. When such bridge symptoms are experienced, there is an increased likelihood that an individual will experience co-morbidity of major depressive disorder and generalized anxiety disorder, suggesting that some symptoms are more predictive of a disorder being observed than other symptoms. In addition, network analyses can identify nodes that are centrally located in the network. The identification of such nodes could provide clinicians with some guidance on which symptoms to prioritize during treatment in order to optimize the therapeutic intervention.

Another advantage of using network analyses over other analysis techniques such as exploratory and confirmatory factor analyses to examine various psychopathologies is that the latter approaches assume that the symptoms of a disorder (*e.g.,* major depression) are the result of a single, underlying (latent) cause. Unfortunately that single underlying cause has not been discovered yet, suggesting that alternative approaches may be required to further our understanding of the underlying causes of psychopathologies. In the network science approach symptoms are causally related to each other and disorders arise from the interplay between connected symptoms (Borsboom & Cramer, 2013). With respect to the experience of stuttering, methods such as factor analysis would assume that varied experiences related to stuttering map onto a single latent factor, whereas the network science approach emphasizes the pattern of associations among the different kinds of experiences associated with stuttering, without necessarily assuming the presence of an underlying latent factor.

1.2. Network analysis of stuttering

In the present work, we applied the network approach in a slightly different way. Rather than examine the symptoms associated with a psychological disorder, we applied this established approach to the communication disorder of *stuttering* as reflected by the Overall Assessment of the Speaker's Experience of Stuttering for Adults (OASES-A; Yaruss & Quesal, 2006, 2010). The OASES-A is a multidimensional assessment designed to describe the consequences of stuttering in terms of: (a) a speaker's general perceptions about his or her stuttering and speech as a whole; (b) the speaker's affective, cognitive, and behavioral reactions to stuttering; (c) the functional difficulties the speaker may have with communication in key situations; and (d) the negative impact that stuttering may have on the speaker's quality of life. Just as Cramer et al. (2010) found that not all psychological and behavioral symptoms of major depressive disorder and generalized anxiety disorder are equal, we predict that not all experiences related to stuttering will be equal. That is, certain factors may affect one's perceptions and reactions to stuttering more than others. Importantly, the tools of network science enable us to identify *which* factors are more or less influential.

A clearer understanding of the client's own experiences of stuttering has important implications for clinical practice, given that the overall impact of stuttering on people involves more than the production of observable speech disfluencies (Van Riper, 1982; Yaruss & Quesal, 2006). Treatment should not only address the physical aspects of stuttering, but also the less observable aspects of stuttering, such as the speaker's feelings about stuttering and perceived impact on quality of life (Plexico, Manning, & DiLollo, 2005; Quesal, 1989; Yaruss & Quesal, 2006). The results of the network analysis of the stuttering experience network could have important implications for clinical practice. For instance, analyzing the pattern of associations among various experiences of stuttering could reveal important "experiences" by virtue of their central location within the network, which clinicians may want to focus on during therapy. The present exploratory work should be viewed as an illustration of a unique way in which network analyses can be applied to the language sciences (see Vitevitch (2008) and Chan and Vitevitch (2009) for other ways that network analyses can be applied to the language sciences), and as a mini-tutorial on some of the terms and measures employed in this approach.

2. Method

2.1. Overall Assessment of the Speaker's Experience of Stuttering (OASES)

The data were previously collected by Yaruss and Quesal (2006) during the development of the OASES-A. To summarize the method they employed, a total of 183 participants who stutter completed the OASES-A. Participants were contacted via a mailing list of individuals provided by the National Stuttering Association, and thus represented individuals from a variety of different backgrounds and experiences. More information about the data collection procedure can be found in Yaruss and Quesal (2006).

In order to examine the experience of stuttering we created a network representation with each of the 100 questions in the OASES-A being represented as a node, and a connection placed between nodes if the responses to those questions from the 183 participants who stutter that completed the OASES-A (i.e., the data from Yaruss & Quesal, 2006) had a correlation coefficient of ± 0.5 or greater. Previous network analyses of psychological symptoms have excluded correlation coefficients less than $\pm$ 0.3 (*e.g.*, McNally et al., 2015; see also Forbush et al., 2016). In the present case we elected to be more conservative and excluded correlations less than ± 0.5 in order to highlight and subject to further analysis only the most robust relationships in the network. Specific items from the OASES are referred to by main section, subsection, and item number (*e.g.*, item I.A.1 refers to the first item in Section 1, subsection A).

2.2. Network analyses

As in previous symptom networks (*e.g.*, McNally et al., 2015) the R package *qgraph* (Epskamp, Cramer, Waldorp, Schmittmann, & Borsboom, 2012) was used to visualize the network and to compute the following *measures of centrality*: strength, closeness, and betweenness. These centrality measures allow us to identify nodes that reside in an "important" position in the network, with "importance" being defined in slightly different ways and emphasizing different dimensions in the network (Borgatti, 2005). For example, *strength* is the sum of the weighted connections that are incident to a particular node, making a node with many and strong connections more important than a node with few, weak connections. *Closeness centrality* measures the distance from a particular node to all other nodes in the network, so an "important" node is one that is close to many other nodes in the network. *Betweenness centrality* measures the number of times a node appears on the shortest path between two other nodes, so an "important" node is one that acts as a "middleman" for many pairs of nodes in the network.

For all of the centrality measures we use here, higher values reflect a node's greater importance to the network. Despite being conceptually related it is important to note that simulation work by Valente, Coronges, Lakon, & Costenbader, 2008 shows that these measures of centrality are in fact distinct measures. In the case of the stuttering experience network, the identification of central or important nodes may provide clinicians with some guidance on which experiences they may wish to focus on during therapy.

In addition to using centrality measures to identify individual nodes that are "important" in the network (*i.e*., nodes high in betweenness centrality, closeness centrality, and strength) as Cramer et al. (2010) did in their analyses of symptom networks, one could also identify an important *set of nodes* referred to as "key players" (Borgatti, 2006, 2008). This set of nodes, when removed from the network, results in maximally fracturing the network into several smaller, disconnected components (Borgatti, 2006, 2008). By fracturing a connected network into smaller, disconnected components one can disrupt the spread of information through a social network. In the case of the stuttering experience network, identifying nodes that are "key players" may provide clinicians with additional information about which experiences are "important" and that clinicians may wish to focus on during treatment.

Another common way to analyze a network that may be useful to speech and language scientists and clinicians attempts to find communities in the network via *community detection analysis* (*e.g.*, Siew, 2013). A *community* is a sub-group of nodes within the network that are more connected to each other than they are with nodes outside of the community (Newman, 2006). In the case of the stuttering experience network, the presence of communities represent clusters of experiences related to stuttering that tend to occur together and may reflect commonalities among these experiences.

3. Results

Fig. 1 shows the network that results from using each item of the OASES-A as a node, and placing connections between nodes if the responses to those questions had a correlation coefficient of ± 0.5 or greater. Thicker lines represent correlations that approach $\pm$ 1, whereas thinner lines represent correlations closer to ± 0.5. Visual inspection of the network shows that several items from Section I of the OASES-A related to "knowledge" about stuttering (i.e., the 5 questions from Section I.B, which assess one's knowledge about stuttering and its treatment) form a small component that is not connected to the rest of

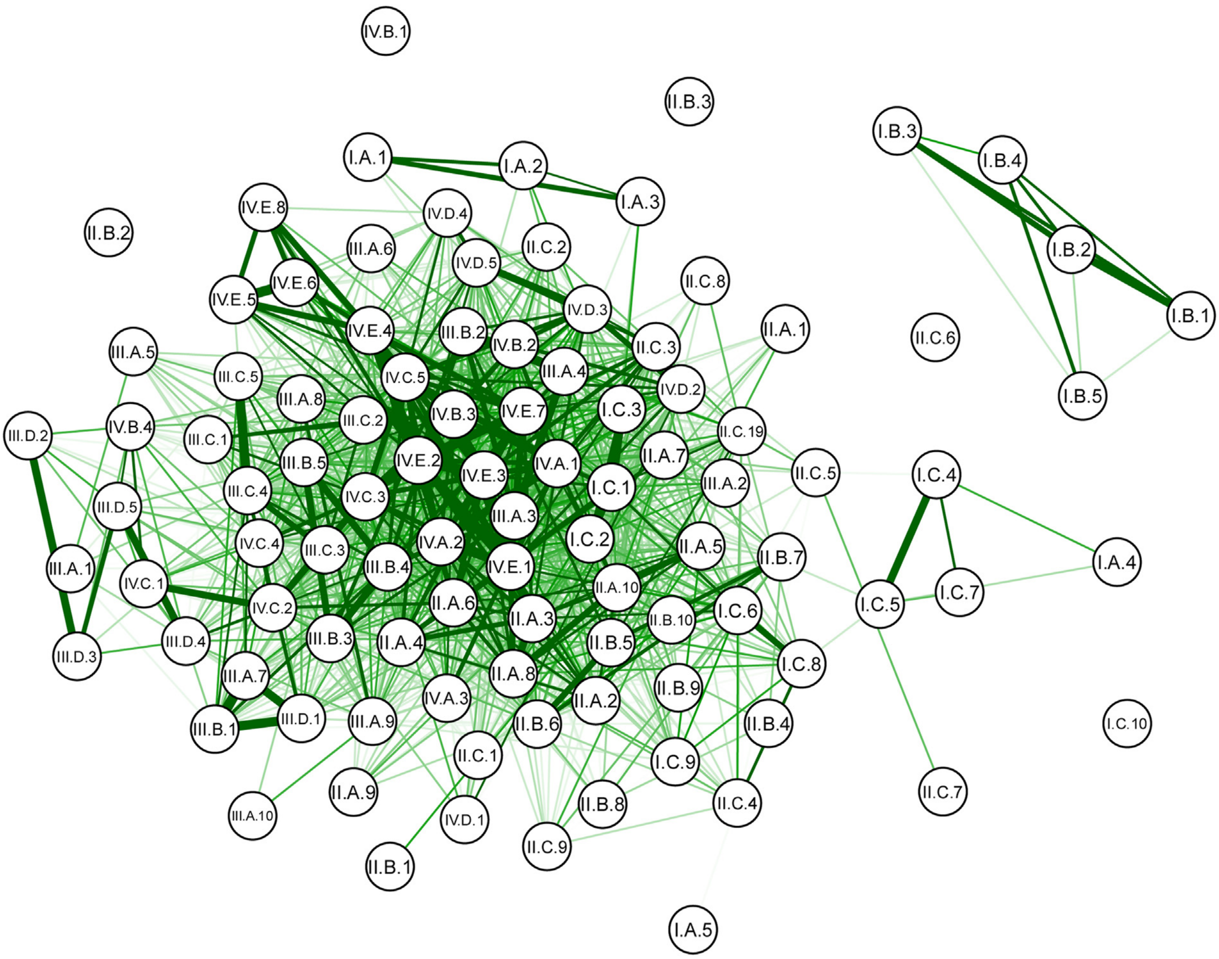

Fig. 1. The network formed by pair-wise correlations of the 100 items in the OASES-A. Connections are shown only if the correlation co-efficient was ±0.5 or greater. Thicker lines indicate that the correlation coefficient was closer to ±1. All the lines are green, indicating that all the correlations were positive. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

the network. Similarly, five other nodes—related to how the client reacts to their own stuttering and how stuttering affects the quality of the client's life—were not connected to the rest of the network or to each other (such nodes are referred to as isolates). These questions included: I.C.10, II.B.2, II.B.3, II.C.6, and IV.B.1.

The fact that these aspects of the experience of stuttering are not as strongly related to other factors contributing to adverse impact is potentially surprising given the widely-held belief in other health-related areas that disease-specific knowledge is related to quality of life (*e.g.*, Suckow et al., 2016) or enhanced coping skills (Moradkhani, Kerwin, Dudley-Brown & Tabibian, 2011). Although the results of our analysis suggest otherwise, people who stutter nevertheless still benefit from learning more about what is happening physically during the moment of stuttering (Van Riper, 1973). Even though such information may not be strongly related to other measures of the impact of stuttering, it does provide a meaningful foundation for therapy strategies aimed at changing speech fluency and reducing negative reactions to stuttering.

3.1. Centrality measures

Fig. 2 shows three plots indicating the betweenness centrality values, the closeness centrality values, and the strength values for each of the 100 nodes in the OASES-A network. The section numbers for the 100 items from the OASES-A are on the left axis of Fig. 2.

Betweenness centrality measures the number of times a node appears on the shortest path between two other nodes. The shortest path is defined as the fewest number of connections that need to be traversed to get from one node to another. (Note that the length of the lines in Fig. 1 should not be interpreted as distance, they are of varying lengths only to aid in visualization of the network.) For example in Fig. 1 the shortest path from I.B.4 to I.B.5 is the direct connection between those 2 nodes. Another way to get from I.B.4 to I.B.5 is to follow the connections from I.B.4 to I.B.1 to I.B.3 to I.B.2 to I.B.5; this is not the shortest path between I.B.4 and I.B.5.

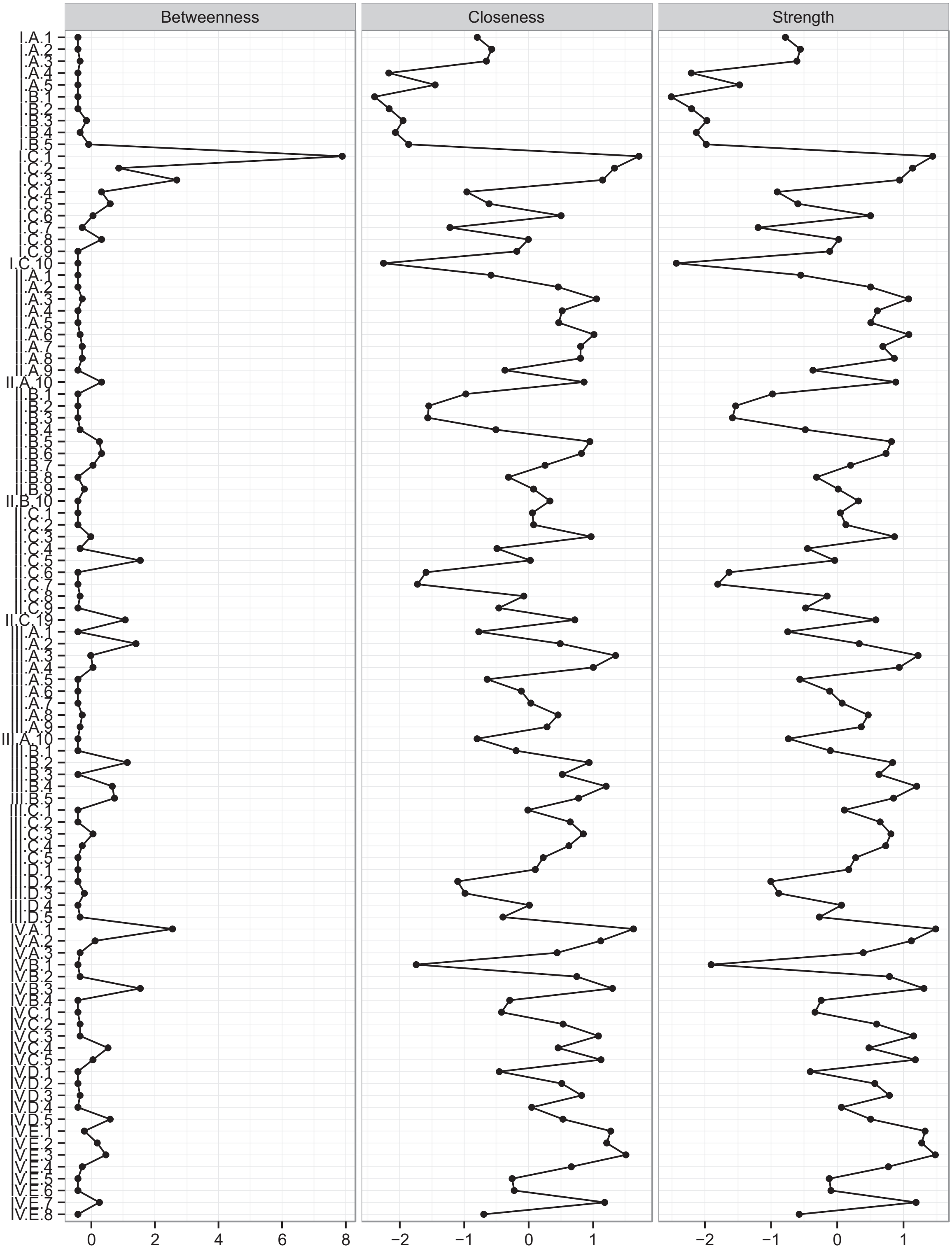

Fig. 2. The values for betweenness centrality, closeness centrality, and strength for the 100 nodes in the OASES-A network. The axis on the left lists the section numbers used to represent the 100 items from the OASES-A. The bottom axes represent the magnitude of the three different centrality measures. These values were standardized and scaled relative to the largest value for each centrality measure.

A node is said to be high in betweenness centrality if it lies along many shortest paths between any two nodes in the network; a node is low in betweenness centrality if it lies along few shortest paths between any two nodes in the network. Listed are the five nodes highest in betweenness centrality (in decreasing order): (1) how one feels about their speaking ability (I.C.1), (2) how they sound when speaking (I.C.3), (3) how stuttering affects one's quality of life (IV.A.1), (4) the extent to which the client feels they can control their stuttering (II.C.5), and (5) the extent to which stuttering interferes with communicating in social situations (IV.B.3). Thus, in order to get from one node in the network to another node in the network while traversing the fewest connections possible it is likely that one will have to go through one of these five nodes that are highest in betweenness centrality.

Closeness centrality is defined as the inverse of the sum of distances from a particular node to all other nodes in the network. High closeness indicates a short average distance between a given node and all other nodes in the network, whereas low closeness indicates a longer distance (i.e., more connections must be traversed) to get from a given node to all other nodes in the network. Listed are the five nodes highest in closeness centrality (in decreasing order): (1) how one feels about their speaking ability (I.C.1), (2) how stuttering affects one's quality of life (IV.A.1), (3) how stuttering affects one's self-confidence (IV.E.3), (4) the extent to which stuttering interferes with communicating in a specific type of social situation (III.A.3), and (5) how effectively one feels they can communicate (I.C.2). Thus, one can get from one of these five nodes that are high in closeness centrality to any other node in the network by traversing relatively few connections. For nodes low in closeness centrality, many more connections would need to be traversed to get from them to other nodes in the network.

Strength is defined mathematically as the sum of the weighted connections that are incident to a particular node. In the present case, strength is obtained by adding together the correlation coefficients on each of the connections of a given node. Listed are the five nodes highest in strength (in decreasing order): (1) how stuttering affects one's quality of life (IV.A.1), (2) how stuttering affects one's self-confidence (IV.E.3), (3) how one feels about their speaking ability (I.C.1), (4) how stuttering affects one's self-esteem (IV.E.1), and (5) the extent to which stuttering interferes with communicating in social situations (IV.B.3). Thus, these five nodes have many and/or strong (as measured by the correlation coefficient) connections, whereas nodes low in strength have few or weaker connections.

It is interesting that the three different measures of centrality (which measure different dimensions of "importance" as shown in Valente et al., 2008) identified several of the same nodes in their "top 5" lists: I.C.1 (feelings about one's ability to speak) and IV.A.1 (the extent to which one's quality of life is negatively affected by stuttering). Note that IV.B.3 (the extent to which stuttering interferes with communication in social situations) was in the top 5 list for betweenness and strength, but was the 6th highest node in closeness centrality. Despite not being in the top 5 on all three centrality measures (a somewhat arbitrary cut-off), IV.B.3 nevertheless was ranked quite high in all three measures; therefore, we will include IV.B.3 in the present discussion. The identification of these three nodes as being central or "important" in the network may provide clinicians with some guidance on which experiences they may wish to focus on during therapy, thereby maximizing the limited time that clinicians have with clients. Furthermore, as suggested by the work of Cramer et al. (2010) on psychopathology symptoms, focusing treatment on these three experiences may result in benefits spreading to connected nodes (i.e., related experiences of stuttering) without having to specifically treat those other experiences directly or explicitly, further increasing the benefits derived from the limited time that clinicians have with clients.

3.2. Key player analysis

Another way to identify nodes that may be "important" in a network is to do a key player analysis (Borgatti, 2008). *Key players* are node(s) that, when removed from the network, result in maximal fracturing of the network into several smaller components. The optimal set of key players is determined by a measure known as *fragmentation*, which indicates the proportion of nodes in the network that can no longer be reached once the set of key players have been removed. The minimum fragmentation value of 0 indicates the network consists of a single component (i.e., it has not fractured), and the maximum fragmentation value of 1 indicates the network has been completely fractured, solely consisting of isolates, or nodes with no connections (i.e., every node is unreachable; Borgatti, 2006).

To fracture the network we elected to remove a set containing 10 nodes, which constituted the removal of 10% of the network. Additional analyses with larger or smaller set sizes did not produce substantial differences in fragmentation values. The removal of the set of 10 nodes listed below resulted in a fragmentation score of 0.45. The value of the fragmentation score obtained in this network indicates that it was still fairly well connected (i.e., one can still reach over half of the nodes in the network) even when 10% of the network was removed. For comparison the key player analysis in Forbush et al. (2016) found that the removal of 3 specific nodes fractured the network of 45 eating disorder symptoms with a fragmentation score of 0.79. That is, the removal of less than 10% of the network in Forbush et al. resulted in much more damage to that network than in the present case, further indicating that the OASES-A network is highly interconnected.

The set of 10 key players included: how one feels about their speaking ability (I.C.1), how they sound when speaking (I.C.3), the extent to which stuttering interferes with communicating in certain situations (III.A.3, III.B.5, IV.B.3), how one feels about their ability to communicate (I.C.8, II.A.10, II.C.4, II.C.10) and the extent to which the client feels they can control their stuttering (II.C.5). Note that this is not an ordered set, meaning one node in the set of key players is not more "important" than another. Rather, together the nodes represent the set of nodes that maximally disconnects the network. To order the nodes in terms of "importance" would be to form a sequence (such as the "top 5 lists" we reported for the three centrality measures) rather than forming a set of elements (see Vitevitch and Goldstein (2014) for another use of key players, as well as for a discussion of how this type of analysis differs from a sequence and other related concepts).

Note also that the nodes for I.C.1 and IV.B.3 appeared in the set of key players and were also identified as being "important" in the centrality measures we computed above (i.e., betweenness, closeness, and strength). The appearance of these two experiences of stuttering by two very different methods for identifying "important" nodes in a network further suggests that clinicians may wish to focus treatment efforts on changing how clients feel about their speaking abilities (I.C.1) and changing clients' perceptions of how much stuttering interferes with their satisfaction with communication in social situations (IV.B.3) in order to make the most of the limited time they have with clients.

3.3. Community detection analysis

The Louvain community detection method (Blondel, Guillaume, Lambiotte, & Lefebvre, 2008) was used to identify communities in the network. Recall that a community is a sub-group of nodes within the network that has more connections to each other than to nodes outside of the community (Newman, 2006). Communities should not be confused with components, which are sub-groups that are disconnected from the rest of the network (see our discussion above about the "knowledge of stuttering" component). In the case of communities, the nodes are still connected to the rest of the network; these nodes just tend to have *more* connections to other nodes in the community than to nodes outside of that community. It is convention to exclude from community detection analyses smaller (dis)connected components (such as the small component of "knowledge of stuttering" items), and isolates (such as the five isolates in the present network) and focus only on the largest component.

Modularity, Q, is typically used to measure the extent to which clear, well-defined communities are found in a network (Fortunato, 2010). For a formal definition of Q see Newman (2004). Positive Q values close to the maximum of +1.0 indicate the presence of clear, well-defined communities in the network. In the present analysis of the OASES-A network $Q = +0.155$, indicating that the communities detected in the largest component of this network may not be particularly well-defined. That is, nodes in a given community appear to be well-connected to other nodes in the same community, and also well-connected to nodes in other communities. This observation is consistent with the key player analysis above where the OASES-A network remained fairly well-connected despite the removal of 10% of the network. The community analysis of the largest component of the network revealed the presence of four communities, which approximated the explicit section labels of the OASES-A (see Table 1).

The descriptions of the communities that were obtained in the community detection analysis can be compared to the labels for the sections of the OASES-A: I. *General Information*, II. *Your Reactions to Stuttering*, III. *Communication in Daily Situations*, IV. *Quality of Life*. Although many items from the explicitly labeled sections of the OASES-A were located in one of the communities detected by the algorithm, some of the items from the explicitly labeled sections of the OASES-A appeared in different communities (see Table 1). Observing several experiences related to stuttering in the "wrong" community may reflect a slight difference between the way that clients (*i.e.*, the source of our data for the network analysis) actually experience stuttering, and the way that scientists and clinicians (*i.e.,* the individuals who developed the OASES-A; Yaruss & Quesal, 2006) perceive and treat stuttering.

4. General discussion

In the present study, network analyses were used to examine the experiences associated with stuttering as assessed by the OASES-A (Yaruss & Quesal, 2006, 2010). These analyses revealed several interesting aspects of the stuttering experience network that would not have been detected otherwise. Given that the perceptions of the person who stutters are a critical component of successful therapy (Plexico et al., 2005; Quesal, 1989), we briefly describe below the implications that the results of the present network analyses could have for clinical practice.

The identification of nodes I.C.1 (how one feels about their speaking ability), IV.A.1 (how stuttering affects one's quality of life), and IV.B.3 (the extent to which stuttering interferes with communicating in social situations) as being central or

Table 1
A general description and list of the items from the OASES-A that constituted the four communities detected in the network.

Description of community	Items from the OASES-A
1. Knowledge and feelings about speech techniques	I.A.4, I.C.4, I.C.5, I.C.7
2. The extent to which stuttering interferes with personal relationships, quality of life, and self-esteem	II.A.4, II.A.6, II.C.2, IV.A.3, IV.C.1, IV.C.2, IV.C.3, IV.C.4, IV.C.5, IV.D.4, IV.D.5, IV.E.2, IV.E.3, IV.E.4, IV.E.5, IV.E.6, IV.E.7, IV.E.8
3. The emotional and physical reactions one has to stuttering and how they may interfere with professional performance	I.A.5, I.C.6, I.C.8, I.C.9, II.A.1, II.A.2, II.A.3, II.A.5, II.A.7, II.A.8, II.A.9, II.A.10, II.B.1, II.C.1, II.C.3, II.C.4, II.C.5, II.C.7, II.C.8, II.C.9, II.C.10 IV.A.1, IV.A.2, IV.B.2, IV.D.1, IV.D.2, IV.D.3, IV.E.1
4. How difficult it is to speak in various daily situations, and strategies one might employ to avoid those situations.	I.A.1, I.A.2, I.A.3, I.C.1, I.C.2, I.C.3, II.B.4, II.B.5, II.B.6, II.B.7, II.B.8, II.B.9, II.B.10, III.A.1, III.A.2, III.A.3, III.A.4, IIIA5, III.A.6, III.A.7, III.A.8, III.A.9, III.A.10, III.B.1, III.B.2, III.B.3, III.B.4, III.B.5, III.C.1, III.C.2, III.C.3, III.C.4, III.C.5, III.D.1, III.D.2, III.D.3, III.D.4, III.D.5, IV.B.3, IV.B.4

important in the network may provide clinicians with some guidance on which experiences they may wish to prioritize during therapy. Because the experience associated with a specific node may trigger closely connected nodes (*i.e*., related experiences), targeting treatment of these "important" nodes may be able to confer benefits to those related experiences despite not being explicitly treated themselves, as the work of Cramer et al. (2010) on psychopathology symptoms suggests. For example, overestimating the extent to which stuttering interferes with communication in social situations may activate other related experiences of stuttering (*e.g.*, it might trigger negative affective or cognitive reactions to stuttering). Focusing treatment on the three "central" experiences identified in the present analysis (*e.g*., how stuttering is perceived to interfere with communication in social situations) may result in benefits spreading to connected nodes (*e.g*., affective or cognitive reactions to stuttering) without having to specifically treat those other experiences directly or explicitly.

Identifying nodes that are key players may provide clinicians with additional information about which experiences they may wish to focus on during treatment. In our analyses the nodes for I.C.1 and IV.B.3 were not only identified as being "important" individuals in the centrality measures we computed (*i.e*., betweenness, closeness, and strength), but they also appeared in the set of key players. The appearance of these two experiences of stuttering in two very different network analyses further confirms that clinicians may wish to focus treatment efforts on changing how clients feel about their speaking abilities (I.C.1) and changing clients' perceptions of how much stuttering interferes with their satisfaction with communication in social situations (IV.B.3).

Visual inspection of the overall network (see Fig. 1) shows that several items from Section 1 of the OASES-A related to "knowledge" about stuttering form a small component that is not connected to the rest of the network. With a less stringent criterion for placing connections between nodes those items might have been weakly correlated with nodes in the rest of the network. Treatment approaches or programs for stuttering typically include an "educational" component where the client and significant other learn about the physiological mechanisms that underlie stuttering (Prasse & Kikano, 2008). Our results suggest that one's knowledge about stuttering may not be strongly related to a variety of other experiences related to stuttering (compare this finding to other health-related areas, *e.g.*, Moradkhani et al., 2011 and Suckow et al., 2016). If the goal of treatment is to alleviate psychological distress that arises due to the client's subjective experiences of stuttering, perhaps less of an emphasis on the education of stuttering during treatment is warranted and more of the clinician's time and energy could be directed toward working through experiences that have been identified as being highly central to the experience of stuttering (for a review of interventions for stuttering see Baxter et al., 2015).

Finally, the community detection analysis revealed that although many items from the explicitly labeled sections of the OASES-A were located in one of the communities detected by the algorithm, some of the items from the explicitly labeled sections of the OASES-A appeared in different communities (Table 1). This finding may reflect a slight difference in the way that clients experience stuttering and the way that scientists and clinicians experience and treat stuttering (see Yaruss and Quesal (2006) for the methodological details behind the development, and reliability and validity assessment of the instrument). Being cognizant of how one's scientific and clinical training might alter one's perception and interpretation of a phenomenon may provide future scientists and clinicians with some guidance as they revise or develop new assessments for various speech, language, or hearing disorders.

5. Conclusion

The present network analysis illustrates how this approach might be applied in other areas of the speech, language, and hearing sciences to gain new insights into various disorders and their treatment. Although some of the results of such analyses may confirm what we already know, other results may provide future scientists and clinicians with important insights that had previously escaped detection. We encourage more scientists and clinicians to employ the tools of network science to examine directly speech, language, and hearing processes, similar to the approach taken in Chan and Vitevitch (2010), Vitevitch and Castro (2015), or Beckage, Smith & Hills (2011). Network analyses might also facilitate the examination of symptoms associated with speech, language, and hearing disorders, following the approach taken in Cramer et al. (2010) with psychological disorders and in the present analysis. Finally, more recent work looking at changes in network structure over time (*e.g*., Starnini, Baronchelli, Barrat & Pastor-Satorras, 2012) might prove useful to language scientists trying to understand how some people who stutter "grow out of it" whereas others do not (or to examine changes that occur in other speech, language, and hearing disorders). We hope the present work illustrates some of the ways that one can use the tools of network science to examine their area of interest.

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