JESK
J Ergon Soc Korea 2015; 34(5): 377-399
http://dx.doi.org/10.5143/JESK.2015.34.5.377
http://jesk.or.kr eISSN:2093-8462

Mapping Studies on Visual Search, Eye Movement, and Eye track by Bibliometric Analysis

Ye Lim Rhie[1], Ji Hyoun Lim[2], Myung Hwan Yun[1]

[1]Department of Industrial Engineering, Seoul National University, Seoul, 05030
[2]School of Design and Human Engineering, Ulsan National Institute of Science and Technology, Ulsan, 44919

Corresponding Author
Ji Hyoun Lim
School of Design and Human Engineering, Ulsan National Institute of Science and Technology, Ulsan, 44919
Mobile : +82-10-3811-4262
Email : smilelim@gmail.com

Received : April 03, 2015
Revised : May 02, 2015
Accepted : May 06, 2015

Objective: The aim of this study is to understand and identify the critical issues in vision research area using content analysis and network analysis.

Background: Vision, the most influential factor in information processing, has been studied in a wide range of area. As studies on vision are dispersed across a broad area of research and the number of published researches is ever increasing, a bibliometric analysis towards literature would assist researchers in understanding and identifying critical issues in their research.

Method: In this study, content and network analysis were applied on the meta-data of literatures collected using three search keywords: 'visual search', 'eye movement', and 'eye tracking'.

Results: Content analysis focuses on extracting meaningful information from the text, deducting seven categories of research area; 'stimuli and task', 'condition', 'measures', 'participants', 'eye movement behavior', 'biological system', and 'cognitive process'. Network analysis extracts relational aspect of research areas, presenting characteristics of sub-groups identified by community detection algorithm.

Conclusion: Using these methods, studies on vision were quantitatively analyzed and the results helped understand the overall relation between concepts and keywords.

Application: The results of this study suggests that the use of content and network analysis helps identifying not only trends of specific research areas but also the relational aspects of each research issue while minimizing researchers' bias. Moreover, the investigated structural relationship would help identify the interrelated subjects from a macroscopic view.

Keywords: Bibliometric analysis, Content analysis, Network analysis, Visual search, Eye movement, Eye track

1. Introduction

Studying published literature allows researchers to understand the critical issues of the topic as well as to identify interesting issues by examining, organizing, and analyzing existing studies. As studies on vision are dispersed across a broad range of area, it is difficult to map out the whole research field. Since existing literature reviews on vision have narrowly focused on specific topics to provide readers up-to-date knowledge, it would be meaningful to categorize the overall research area and observe relationships. In this paper, bibliometric analysis is applied to assist researchers in understanding and identifying critical issues. Bibliometric analysis is defined as a technique that enables quantitative and statistical analysis of literatures (Broadus, 1987; Pritchard, 1969). Bibliometric information such as title, abstract, author, and keyword is used for counting, comparing, and measuring quantities (Ziegler, 2009), Strength of bibliometric analysis has been verified and increasingly applied in various study fields (Allen et al., 2009; Hood & Wilson, 2001). In this study, content analysis and network analysis were conducted based on title, abstract, and keyword information of literatures. Content analysis focuses on extracting meaningful information from various types of sources including text, image, and video (Downe-Wamboldt, 1992). It takes one step further from merely describing the current status to allow researchers quantitative and qualitative exploration of the data and find issues (Morgan, 1993). Network analysis is the empirical methodology that focuses on the patterns of relationships of the objects, rather than the objects themselves (Haythornthwaite, 1996). Co-author relations (Kretschmer & Aguillo, 2004; Otte & Rousseau, 2002), co-citation relations (Cronin & Overfelt, 1994; Price, 1976; Wagner & Leydesdorff, 2005), and co-word relations (Bhattacharya & Basu, 1998; Callon et al., 1983) have been investigated through network analyses.

As a sensory input channel, vision is the most influential factor in information processing, and has been studied in a wide range of studies. In physiological studies, eye movements are typically classified into 'fixations', 'saccades' and 'smooth pursuit eye movements', whereas psychological researches attempted to identify subjects' intentions with ocular motor behavior based on the assumption that ocular behavior reflect cognitive processes (Barnes, 2008; Eriksen & Schultz, 1979; Koch & Ullman, 1987; O'Regan, 1992; Rensink, 2000; Wolfe, 1999). As studies on vision are dispersed across a broad area of research, the scope of narrative reviews of such articles have been confined to particular eras (Carrasco, 2011; Cavanagh, 2011; Kowler, 2011), topics (Owsley & McGwin, 2010; Schütz et al., 2011), or to certain publishers (Mele & Federici, 2012).

Cavanagh (2011) explored studies on 'visual cognition' conducted in the last twenty five years, and attempted to explain the concepts of visual executive function, stimulus characteristics, objects and environments to review the studies on cognitive system. Kowler (2011) reviewed articles published from 1986 to 2011 on the physical eye movement according to the order of three keywords: 'gaze control', 'smooth pursuit eye movement' and 'saccade'. Carrasco (2011) limited the research on psychophysical studies of 'visual attention' with behavioral effect. Mele and Federici (2012) selected 46 articles from 1998 to 2010 which match a set of specific criteria and classified them into studies on developmental age, human-computer interaction, cognitive process, and assistive technology. Owsley and McGwin (2010) reviewed studies on vision within the context of driving, summarized the current status of researches and raised issues on driving performance and safety.

Studies on visual attention, eye movement, and eye tracking share common topic of vision, but the interactions between each topic have been explained only intuitively. To quantitatively investigate macroscopic study trend, some researchers analyzed counts of publication retrieved in an interested year along literature review (Braddick & Atkinson, 2011; Carrasco, 2011). However, as they only provide simple count statistics as their result, a general trend on the area and the interactions between each research topics are yet to be identified. In addition, a closer examination is needed since a single search keyword can be used to retrieve two or more papers with different topics.

Bibliometric analysis based on the massive meta-data could help us to find unexpected interactions between study areas (Porter & Cunningham, 2005; Saka & Igami, 2007), as well as to identify the trend of research in a broad high-level view (Estabrooks et al., 2004). In this study, the researchers conducted content analysis and elicited seven major categories composing studies. Macroscopic relations within the area of vision research were also observed based on the meta-data of literature by bibliometric analysis. Through the research, we tried to configure the benefit of bibliometric analysis, and compare the result with the instinct suggested in narrative literature review.

2. Method

To retrieve published articles, three search keywords were selected: 'visual search', 'eye movement', and 'eye track' to investigate visual information processes, physiological studies and practical observational techniques.

In the first stage, literature information was collected by querying the selected keywords in Science Direct (http://www.sciencedirect.com) and Scopus (http://www.scopus.com) database. The top 3,000 articles were screened against Sciverse sorting criteria (ScienceDirect, 2013). Keyword information of retrieved articles was collected as structured information, while title and abstract information were collected as unstructured information because the information was stored in the form of natural language. More detailed procedure is described in the previous study of Rhie et al. (2014).

After conducting content analysis on both types of information, it was observed that only structured information was able to reveal research objectives effectively. Therefore, network analysis was conducted only on the structured form as shown in Figure 1.

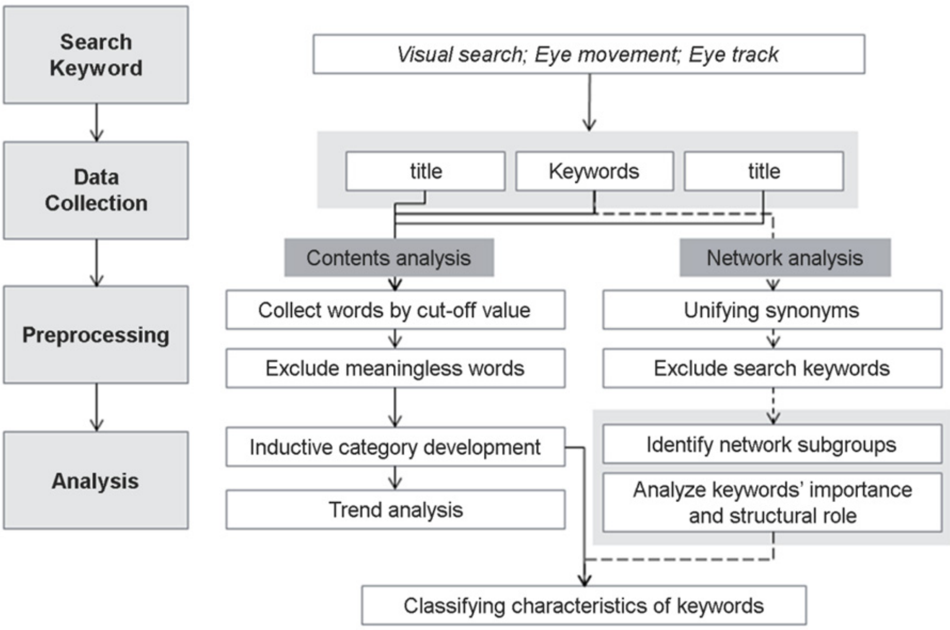

Figure 1. Process of content analysis and network analysis

Content analysis enables quantitative research on qualitatively expressed data (Kondracki et al., 2002), allowing researchers to infer the importance of concepts from the frequency of words and instances. Content analysis is divided into qualitative content analysis and quantitative content analysis; the former attempts in-depth interpretation with a set of encoding rules from innate nature of the data, while the latter only aims to describe encoded information using external algorithms (Morgan, 1993).

In preprocessing, plural forms and synonyms were converted to one representative keyword and stop words such as prepositions and articles were excluded. Inductive categorical processes were applied on the meta-data of articles retrieved by the three keywords, and differences were identified in the results. The articles published in the last five years were separately collected to be analyzed along the same lines.

Network Analysis, which is used in a wide range of areas, is a methodology that observes structural relations and patterns between a given set of objects (Borgatti et al., 2009; Freeman, 2004). For example, a patent network is used to identify relations between technologies (Yoon & Park, 2004), while a user's Value Map depicts and identifies the user's hidden needs (Kim et al., 2012).

Preprocessing for network analysis includes cleansing the dataset by unifying plural forms and synonyms into a representative keyword, which become the nodes of a network. The edges between them are counted when they appear in the same document and defined in the form of co-occurrence relation matrix.

Centrality measures were calculated using UCINET 6.0 (Borgatti et al., 2002) software, and relational structure was visualized using Netdraw 2.123 (Borgatti, 2002). These measure the importance of keywords in a network (Opsahl et al., 2010). In this study, degree centralities, betweenness centralities, and eigenvector centralities were calculated to quantitatively analyze the importance of each keyword.

Degree centrality of a node simply refers to the number of edges directly connected to the node. To identify the importance of the keywords on the whole network, numerical calculation in equation (1) (Wasserman & Faust, 1994) where 'D' is the 'degree centrality', deg (n_i) represents the number of keywords co-occurring with the keyword n_i, and g refers to the number of total keywords.

$$C_D(n_i) = deg(n_i) \qquad (1)$$

In literature review, degree centrality would represent the number of the keywords studied in journals. As the papers were collected based on relevance criteria, terms closely related to the search keywords would have a higher degree centrality than others.

Betweenness centrality of a node (Freeman, 1977) defines the role of nodes as the intermediary within the whole network structure. The equation (2) calculates the betweenness centrality; $b_{ij}(P_i)$ refers to the ratio of the number of shortest paths when a given node P_i is excluded against the number of shortest paths including the given node P_i.

$$C_B(n_i) = \sum_{i \neq j \neq k}^{n} b_{ij}(P_k) \qquad (2)$$

While degree centrality focuses on frequency, betweenness centrality focuses on the importance of the structural role of bridging keywords. Therefore, keywords having high betweenness centrality would play an intermediary role between different areas of study.

Eigenvector centrality of a node (Borgatti et al., 2009) measures the overall importance of a node using factor analysis to reduce the closeness centrality of low-scoring sub-networks. For a node *v* with neighborhood nodes *M(v)* and their adjacency matrix represented as $a_{v,t}$ where *v* and *t* are nodes, the formula (3) can be used to calculate the eigenvectors based on the equation Ax = λx; here, λ refers to the eigenvector centrality.

$$x_v = \frac{1}{\lambda}\sum_{t \in M(v)} x_t = \frac{1}{\lambda}\sum_{t \in G} a_{v,t}\, x_t \qquad (3)$$

The eigenvector centrality of a node can be interpreted as the influence of the node on the whole network. In other words, the overall importance of a keyword within each area of study may be observed.

These centrality measures enable the identification of structural characteristics of networks and allow comparisons between the search keywords.

In addition, a quantitative evaluation of clusters of nodes is possible by using the Girvan-Newman subgroup algorithm.

Girvan-Newman subgroup algorithm (Girvan & Newman, 2002) detects communities in complex systems by eliminating the node with the highest betweenness centrality between iterations. Modularity is represented by the 'Girvan-Newman's modularity Q', the difference between the number of edges in clusters elicited by the algorithm and the number of edges in clusters based on random assignment. It can be calculated by the equation (4), where m is the number of clusters, A_{ij} is the adjacency matrix when s_i is 1 when s_i belongs to group i, and 0 otherwise.

$$Q = \frac{1}{4m} \sum_{ij} \left(A_{ij} - \frac{k_i k_j}{2m} \right) (s_i s_j + 1) \qquad (4)$$

Girvan-Newman algorithm allows researchers to set the number of sub-groups with 'Girvan-Newman's modularity Q'. In this study, sub-groups with the highest Q-value were elicited for analysis. Sub-groups demonstrated specific studying areas connected by keywords of high betweenness centralities.

3. Results of Content Analysis

3.1 Keywords categories

Titles, abstracts, and keywords of published articles were collected by using three query keywords: 'visual search', 'eye movement', and 'eye track'. The first 1,000 articles and books were collected from ScienceDirect (http://www.sciencedirect.com) and the first 2,000 articles, proceedings, and review articles were collected from Scopus (http://www.scopus.com), sorted using the relevance criterion defined by Sciverse (ScienceDirect, 2013). In the same way, 3,000 papers from 2009 to February 2013 were collected in the same way. For the collected words, only 1,000 of the most common terms were considered for each search keywords in further analysis. Terms exceeding the cut-off value are listed in Appendix A.

Among the collected papers, the volumes of 1,951, 1,933, and 1,573 contained keyword information on 'visual search', 'eye movement' and 'eye track' search keyword respectively. Similarly, the number of articles collected within the year 2009 and 2013 was 2,742, 2,238, and 1,366 respectively. Data was cleaned to combine plural and singular forms and eliminate stop words such as prepositions, articles and pronouns. To obtain 100 most frequent terms among unstructured and structured words, a cut-off value was deployed to preserve terms for further analysis in each search result. For unstructured information, cut-off values which border one hundred terms with others were 255, 300, and 248 for all eras, while the respective cut-off values of 253, 302, and 159 were used for information pertaining from the year 2009 to 2013 retrieved from search keywords. For structured information, keywords counted more than 10, 9, 6 for all era, and 8, 10, 4 for recent five years were collected.

Based on inductive categorization procedure (Mayring, 2000), content analysis was conducted. Similar keywords were grouped and each groups were repeatedly merged until the following seven categories remained; 'stimuli and task', 'condition', 'measures', 'participants', 'eye movement behavior', 'biological system', and 'cognitive process'. The resulting categories were similar to the categories that Rayner (1998) classified on eye movements when reading: (a) the characteristics of eye movements, (b) the perceptual span, (c) integration of information across saccades, (d) eye movement control, and (e) individual differences. In this study, experimental terms such as 'stimuli and task' and 'condition' were added. Each category is defined in Table 1.

Table 1. Example of terms on seven deducted categories

Category	Definition	Example
Stimuli and task	Visual subject or acoustic cue given	Vision, 3D, Reading, Video, Computer vision, …
Condition	Controlling factors such as shape, brightness, contrast, structure, and environment	Multiple object, Density, Dynamic, Depth, …
Measures	Features that can be measured	Face detection, Gaze tracking, Particle filter, Eye position, Camera, …
Participants	Participants' characteristics or controlled condition	Human, Schizophrenia, Children, ADHD, Glaucoma, …
Eye movement behavior	Observable physical eye movement	Eye movements, Smooth pursuit, Tracking, Saccade, Gaze, …
Biological system	Neurological or physical organs /mechanism	Eye, Frontal eye field, Ocular reflex, Cerebellum, Vestibulor, …
Cognitive process	Psychological effect or adaptation in eye movement	Attention, Modeling, Prediction, Motion, Visual attention, …

3.2 Content analysis on unstructured and structured information in articles

The proportion of each category within the structured and unstructured information retrieved from the three search keywords is shown in Figure 2. Terms related to experimental studies were placed on the left side of the graph without patterns, and terms related to theoretical studies were posited on the right, filled with patterns. Studies on 'eye movement behavior' were colored in white to represent the study area generally covers both experimental and theoretical topics. Structured and unstructured information showed a significant difference in terms of categorical distribution within each study area (visual search: $\chi^2=3996.489$; $p<0.001$, eye movement: $\chi^2=790.099$; $p<0.001$, eye track: $\chi^2=719.882$, $p<0.001$). Keywords from unstructured information contained more terms related to experimental environments, such as stimuli, task and condition, compared to keywords extracted from structured information. This showed that designing stimuli and tasks plays an important role in studying vision. On the other

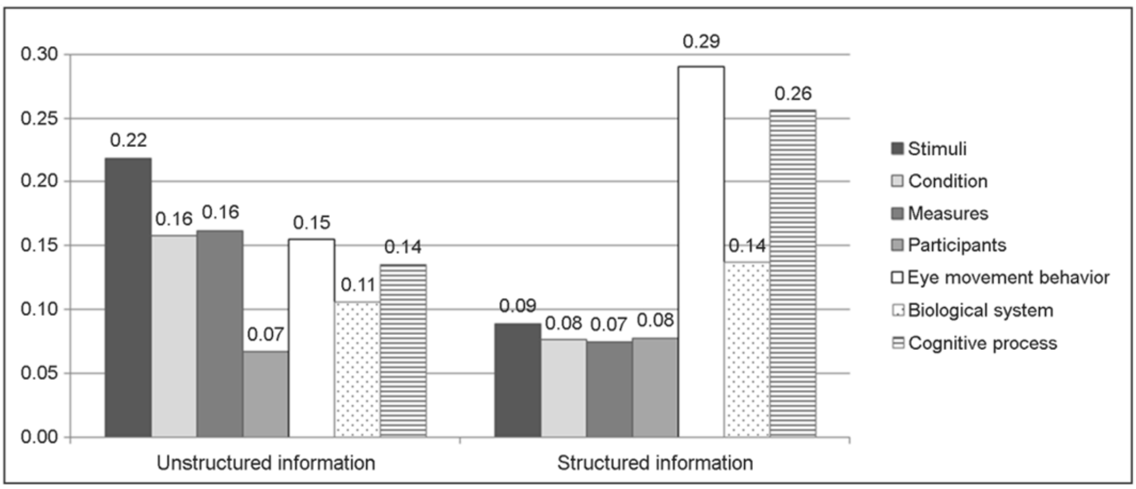

Figure 2. Keywords frequency distribution: comparison between structured versus unstructured information of articles

hand, structured information had larger portions of keywords related to 'cognitive process' and 'physical eye movement' which are closely related to the research subject.

3.3 Chronological analysis of articles on visual search, eye movement, and eye track

Figure 3 shows the keyword frequency distribution for articles published in all years versus the last five years. 'All year' covers from Jan. 1825 to Feb. 2013, and recent study ranges from Jan. 2009 to Feb. 2013. The keywords distribution per group showed a statistically significant difference depending on the search keyword (χ^2=2029.153; p<0.001). Studies on 'visual search' had large portion of keywords related to 'cognitive processes', while those studies in 'eye movement' and 'eye track' had keywords mostly categorized as 'biological system' and 'eye movement behavior'. This showed that 'visual search' studies were usually related to cognitive science and engineering, while 'eye movement' and 'eye track' studies were related to physiological as well as psychological subjects.

Also, keyword distribution between research era was significantly different (visual search: χ^2=163.166; p<0.001, eye movement: χ^2=620.685; p<0.001, eye track: χ^2=193.008, p<0.001). Overall, whereas the frequency of keywords related to experimental studies increased, terms related to 'eye movement behavior' and 'biological system' decreased. Also, studies on 'eye movement' and 'eye track' were more frequent in recent literatures.

This phenomenon showed that studies deploying experiments were increasing with the help of technological advancement on eye trackers as well as fMRIs. Recent eye tracking devices enable realistic studies on 'vision' under various conditions and contexts. Analysis results suggest that empirical and application studies are increasingly conducted to verify the association between 'eye movement behavior' and 'cognitive processes'; to investigate emerging issues based on past physiological and theoretical studies, especially on the field of eye movement.

Figure 3. Keyword distribution categorized by era

4. Results of Network Analysis

Collected keywords were used for network analysis by setting each keyword as a node, and setting the edges based on co-occurrence of keywords. Visualized networks in Figure 4, 5, and 6 demonstrate the keywords whose node strengths are greater than three. Node strength is proportional to the size of stroke widths. Small sub networks which contained fewer than five terms were removed from the analysis. The size of a node represents betweenness centrality, showing the importance in connecting other study areas (Freeman, 1977), whereas the shape indicates subgroups distinguished through the Girvan-Newman subgroup algorithm (Girvan & Newman, 2002). Only keywords having a betweenness centrality higher than 1.0 were labeled 'visual search' and 'eye movement' network. Keywords in each sub-group are listed in Appendix B.

4.1 Network analysis on keyword related to visual search

The network structure of studies on 'visual search' is shown in Figure 4. Girvan-Newman subgroup algorithm demonstrated the highest Q-value (0.456) when the number of groups is 12 and the minimum number of linked nodes is 4. According to the network, keywords related to 'cognitive process' and 'physical eye movement' are located in the middle of the network, whereas studies containing 'condition', 'measuring tool', and 'character of participants' are distributed at the periphery. In addition, keywords related to *visual attention* generated subgroups independent from those related to *attention*. While studies on *attention* mostly encompassed terms on cognitive processes as well as physiology, *visual attention* was mainly related to keywords related to experimental environments such as stimuli and condition. From this, it can be inferred that studies related to *visual attention* tended to focus on experimental approach while *attention* focused on theoretical approach.

The subgroup including terms related to 'stimuli' (e.g. *contrast* and *reading*) was separated from the subgroup including terms

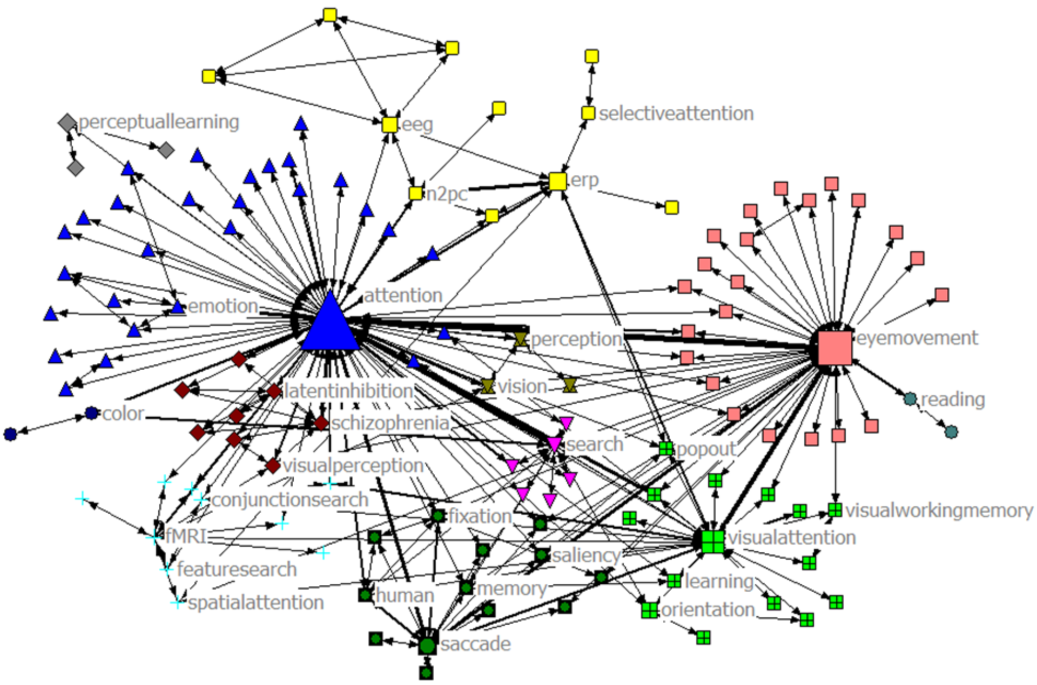

Figure 4. Network of keywords in literature related to 'visual search'.
Node size: betweenness centrality; Node strength: greater than 3; Shape attribute: Girvan-Newman Subgroup (n=12; Q=0.456)

related to types of eye movements (e.g. *saccade* and *fixation*). It was observed that studies related to 'physical eye movement' was bridging studies related to *eye movement* and *visual search* tasks, which suggested that studies on preattentive processes mainly adopted experimental approaches (Deubel & Schneider, 1996; Hoffman & Subramaniam, 1995; Kowler et al., 1995), identifying cognitive factors through characteristics of eye movement by differentiating the condition of stimuli from the environment.

The keywords *ERP* and *fMRI* were located closer to the terms 'cognitive processes' than 'physical eye movement', which implies the usage of tools to measure cognitive factors. It was observed that studies on driving context belonged to the 'physical eye movement' subgroup, which implies that studies on driving tasks mainly focused on *visual attention* in laboratory environments.

Table 2 shows the top ten keywords by each centrality measure (degree centrality, betweenness centrality, eigenvector centrality) ordered by rank. In general, studies which contained 'cognitive process (e.g. attention)' or 'physical eye movement (e.g. eye movement)' in their stated objective had higher centralities than studies with objectives containing terms on experimental environments such as 'stimuli and task (e.g. reading)' or 'participants (e.g. age)'. However, measurement tools such as *ERP* and *fMRI* were ranked high as well; it seems that these tools were used in a wide range of studies in various experimental conditions. The keywords *eye track* and *scene perception* played an important role as mediators connecting different fields, since they had higher betweenness centralities than degree and eigenvector centralities.

Table 2. Centrality measures of keywords in literature related to 'visual search'
Unit: Raw score (Normalized score)

Degree		Betweenness		Eigenvector	
Attention	578 (0.166)	Attention	1,426,822.0 (0.236)	Attention	0.389 (0.551)
Eye movement	466 (0.134)	Eye movement	1,226,511.0 (0.202)	Eye movement	0.288 (0.407)
Visual attention	388 (0.111)	Visual attention	785,910 (0.130)	Visual attention	0.260 (0.367)
ERP	176 (0.051)	ERP	253,777.0 (0.042)	Saccade	0.158 (0.223)
Saccade	174 (0.050)	Saccade	195,546.0 (0.032)	Search	0.121 (0.171)
Search	120 (0.034)	Eye track	169,759.0 (0.028)	fMRI	0.120 (0.169)
fMRI	118 (0.034)	Visual perception	152,302.0 (0.025)	ERP	0.120 (0.170)
Vision	109 (0.031)	Search	125,840.0 (0.021)	Vision	0.117 (0.166)
Reaction time	101 (0.029)	fMRI	118,924.0 (0.020)	Reaction time	0.116 (0.165)
Visual perception	99 (0.028)	Content-based image retrieval	116,662.0 (0.019)	Human	0.103 (0.146)

4.2 Network analysis on keyword related to eye movement

The network of studies related to eye movement is visualized in Figure 5. The results of Girvan-Newman subgroup analysis showed 15 subgroups (Q=0.517), which are characterized by their components. Three subgroups show studies on characteristic of eye movements such as *saccade*, *smooth pursuit*, and *rapid eye movement (REM)*. Two subgroups represent studies on certain tasks such as *reading* and *motion*. These large subgroups are connected to the small subgroups related to the studies on psychology, neurology, genetics, and measuring tools. Among them, studies on neurology were distinguished the studies on *frontal eye field* related to the voluntary eye movement from involuntary eye movement such as *vestibule-ocular reflex*.

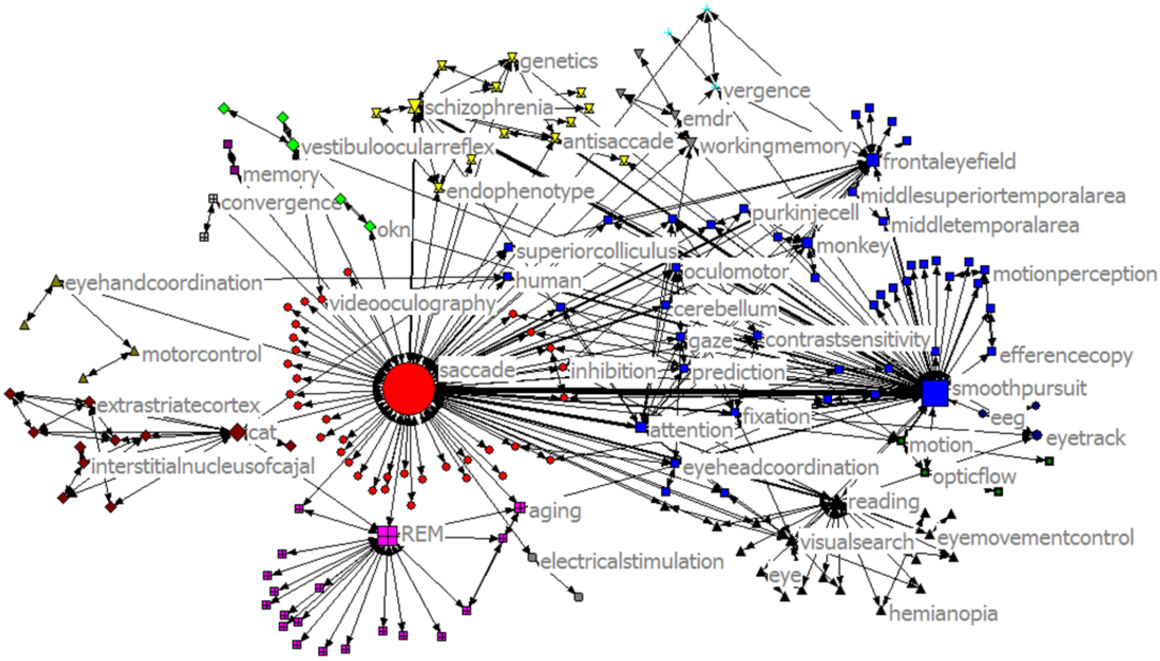

Figure 5. Network of keywords in literature related to 'eye movement'.
Node size: betweenness centrality; Node strength: greater than 3; Shape attribute: Girvan-Newman Subgroup algorithm (n=15; Q=0.517)

Each subgroup represented issues of each studying area: the largest subgroup is represented by saccade, mainly composed of terms related to 'cognitive processes' while the *smooth pursuit eye movement* subgroup had many physiological terms. *Gaze* and *smooth pursuits* are involuntary eye movements to gain clearer vision (Steinman et al., 1973), and as such, they were positioned near the *neurology* subgroup.

Concerning tasks, *reading* assignments are more centralized than *scene perception* or *visual search*; since, as Rayner (2009) pointed out, studies on reading have rapidly progressed than others because the information level of the stimuli can be easily and systematically estimated in experiments.

Keywords on *REM sleep* make up one subgroup, and studies on *superior colliculus*, the part of the brain that operates eye movement, were observed in neurology studies. Overall, physiological keywords were relatively dispersed compared to keywords on 'psychological process', as can be seen in Table 3's keywords. Terms on 'physical eye movement' such as *saccade*, *smooth*

Table 3. Centrality measures of keywords in literature related to 'eye movement'
Unit: Raw score (Normalized score)

Degree		Betweenness		Eigenvector	
Saccade	831 (0.220)	Saccade	2,120,665.0 (0.297)	Saccade	0.423 (0.598)
Smooth pursuit	557 (0.147)	Smooth pursuit	1,012,162 (0.142)	Smooth pursuit	0.304 (0.431)
REM	273 (0.072)	REM	586,013 (0.082)	Attention	0.163 (0.231)

Table 3. Centrality measures of keywords in literature related to 'eye movement' (Continued)
Unit: Raw score (Normalized score)

Degree		Betweenness		Eigenvector	
Eye track	242 (0.064)	Eye track	532,933.0 (0.077)	Frontal eye field	0.145 (0.206)
Attention	226 (0.060)	Attention	344,623 (0.048)	Vestibule ocular reflex	0.132 (0.187)
Reading	199 (0.053)	Reading	332,996 (0.047)	Human	0.121 (0.171)
Frontal eye field	199 (0.053)	Schizophrenia	284,969 (0.040)	Oculomotor	0.113 (0.160)
Vestibulo ocular reflex	193 (0.051)	Vestibulo ocular reflex	275,349 (0.039)	Fixation	0.109 (0.154)
Schizophrenia	190 (0.050)	Frontal eye field	187,551 (0.026)	Schizophrenia	0.104 (0.146)
Human	159 (0.042)	Human	275,349 (0.024)	Eye track	0.104 (0.148)

pursuit and *fixation* had higher centralities than terms related to 'stimuli and task' as well as 'cognitive process'. *Frontal eye field* connected observable eye movements and unobservable cognitive processes, while *vestibulo-ocular reflex* were used to measure infants' eye movements.

4.3 Network analysis on keyword related to eye track

The keyword network on 'eye track' showed a much simpler structure than the two previous networks, implying that issues or topics related to eye trackers are not studied repeatedly, although they had been used in a wide range of fields. Keywords that appeared more than three times were shown in Figure 6 with 6 subgroups (Q=0.363). It shows a radial shaped network centered around terms related to eye movement behavior, which was identical to the search keyword, with high centralities for *eye*

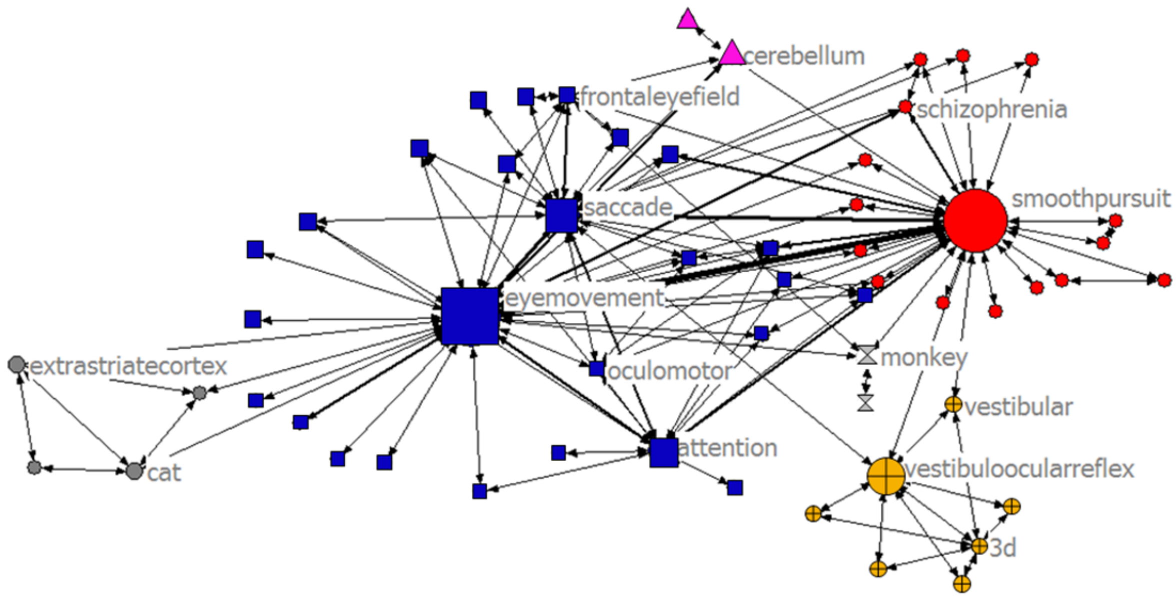

Figure 6. Network of keywords in literature related to 'eye track'.
Node size: betweenness centrality; Node strength: greater than 3; Shape attribute: Girvan-Newman Subgroup (n=6; Q=0.363)

movement, *saccade*, and *smooth pursuit*. Around 'eye movement' keyword, which had the highest centralities, terms related to physiologies, tools, and neurology were distributed. *Attention*, which represents the cognitive factor, belongs to the group of *saccade* and *fixation*, while *smooth pursuit* belongs to the group of physiological terms. As terms on eye movement and cognitive process were revealed as important nodes, it can be inferred that the eye tracker is currently used as a measurement tool, as mentioned by Cavanagh (2011).

Centrality measures were higher in *eye movements*, such as *smooth pursuit*, *saccade* and *gaze*, than *attention* (Table 4). Also, *gaze* and *fixation* had high betweenness centrality and connected *attention* and *eye movement*. Moreover, while terms such as *CR39* and *image process* were not displayed in the visualized network, they had high betweenness centrality. From the results, we may conclude that studies on engineering techniques do exist but with low number of cases.

Table 4. Centrality measures of keywords in literature related to 'eye track'
Unit: Raw score (Normalized score)

Degree		Betweenness		Eigenvector	
Eye movement	616 (0.125)	Eye movement	2,120,787.0 (0.176)	Eye movement	0.395 (0.559)
Smooth pursuit	348 (0.071)	Track	1,388,783.0 (0.115)	Smooth pursuit	0.296 (0.418)
Saccade	283 (0.058)	Smooth pursuit	800,610.3 (0.066)	Saccade	0.270 (0.381)
Attention	162 (0.033)	Saccade	58,488.0 (0.048)	Attention	0.173 (0.244)
Track	152 (0.031)	Gaze	460,967.8 (0.038)	Prediction	0.135 (0.191)
Gaze	147 (0.030)	Vision	430,162.1 (0.036)	Gaze	0.132 (0.187)
Frontal eye field	117 (0.024)	CR39	367,522.6 (0.030)	Oculomotor	0.119 (0.169)
Human	98 (0.020)	Human	339,148.6 (0.028)	Frontal eye field	0.116 (0.165)
Schizophrenia	94 (0.019)	Attention	324,598.1 (0.027)	Motion	0.114 (0.161)
Prediction	92 (0.019)	Velocity effect	281,482.4 (0.023)	Fixation	0.114 (0.161)

5. Discussion and Conclusion

Using the meta-data of literature on 'visual search', 'eye movement', and 'eye track', a bibliometric analysis was conducted with content analysis and network analysis. A general trend underlying the studies on vision was identified by content analysis, while the structure of relationships between research areas was captured via keyword network analysis. The results of this study quantitatively support the findings of existing literature reviews. For example, technology development of eye trackers as well as other measurement tools allowed experimenters to conduct their studies in various environments. Carrasco (2011) pointed out four reasons behind the progress of research in the area of 'visual attention': 'distinction between visual attention area and psychophysics', 'development of neurological studying area', 'technological development of neuroimaging and eye tracker', and 'development of computational model based on brain mechanism and structure'. Braddick and Atkinson (2011) also considered the development of fMRI as one of the most influential factors of progress. Their interpretation on the development of research can be observed in the keyword network analysis on the area of 'visual search'. This network identified a distinction between *visual attention* and *attention*, showing the practical application and impact of measurement technologies such as *ERP* and *fMRI*. These measurement tools acted as a mediator between *attention* and *visual attention* in the network.

This study was also able to illustrate the interaction between research topics. Physiological and cognitive research areas converged to configure the cognitive process by the eye movement, as mentioned in existing review papers. Rayner (2009) mentioned that an increasing trend in the number of studies observing ocular pattern to identify the principle of mind and body, albeit being confined to reading tasks. Kowler (2011) insisted that *prediction*, *learning* and *attention* could be observed by eye movement since these activities are the most influential factors on eye movement. In a likely manner, network analysis also showed an association between 'eye movements' and 'cognitive process'; *gaze* was associated with *attention*, while *saccade* and *smooth pursuit* were liked to physiological terms such as *cerebellum*.

To examine sub-groups divided by Girvan-Newman algorithm, a categorical proportion of each subgroup was calculated based on seven categories derived via content analysis. Each search keywords had a different number of groups: twelve groups for 'visual search', fifteen for 'eye movement', and six for 'eye track'. Terms on 'stimuli and task', 'condition', and 'measures' were regarded to represent experimental studies, whereas terms on 'biological system' as well as 'cognitive process' were considered to be related to the theoretical studies. Terms on 'eye movement behavior' was considered neutral, since they belong both of experimental and theoretical study areas. Figure 7 shows the proportion of each category within the five largest sub-groups in each search keyword. Filled and patterned bars respectively represent experimental and theoretical studies, while the white bars represent neutral property. The proportion of categories demonstrated the characteristic of a specific field of study; for example, psychological and physiological categories were of similar proportion in the sub-group of *visual attention* (VS3), while most of the sub-groups of *attention* would consist mostly of psychological studies. The proportion of 'cognitive process' and 'biological system' determined whether the study is physiological or psychological.

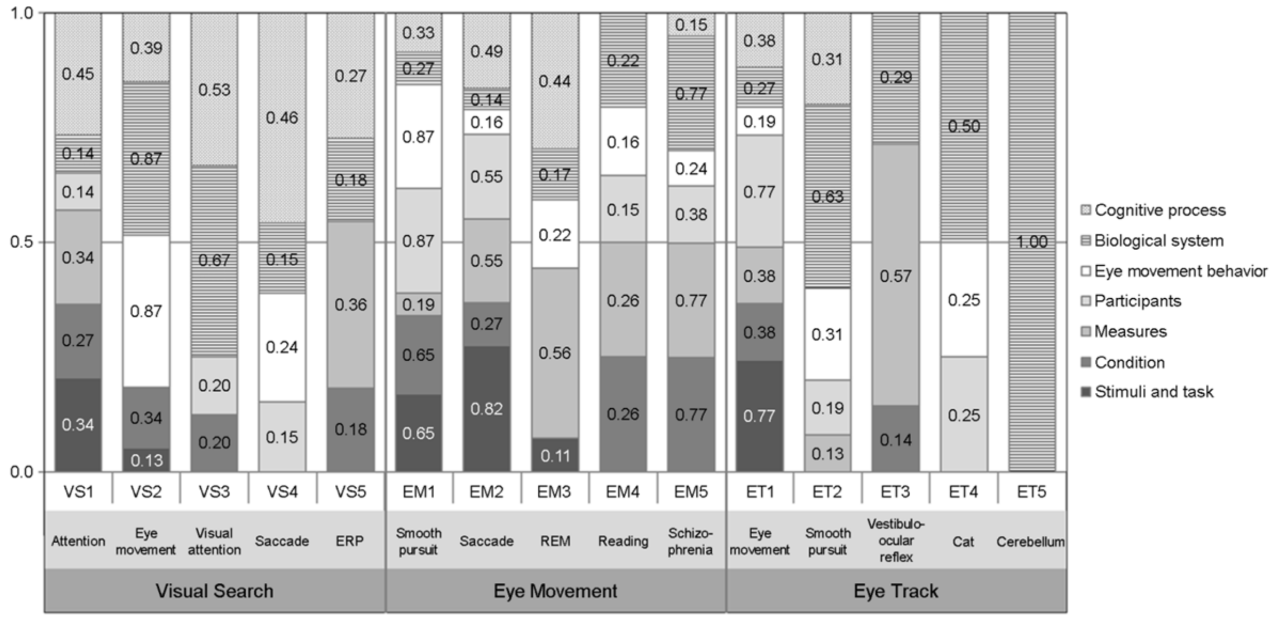

Figure 7. Categorical properties of 'visual search', 'eye movement', and 'eye track'

Although the study tried to eliminate subjective bias, there were several limitations. In selecting search keywords, it cannot be proven whether the collected keywords indeed explains or represents the research area, and another research area could have been brought up during the process of research. In addition, this study ignored isolated networks, which are, separated when the minimum tie strength is four. Also, as Guba and Lincoln (1994) pointed out, subjective bias has the potential to affect the process of categorizing keywords.

Content analysis showed that the number of studies on 'cognitive process' increased, and one of the main reasons was revealed to be the development of measurement tools. Through network analysis, it was observed that studies on neurology and physiology, which used to be carried out independently, were in reality linked to each other through terms related to cognitive process. Reviewing literatures by bibliometric technology was capable of identifying not only trends of specific research areas but also the relational aspects of each research issue while minimizing researchers' bias. Moreover, the investigated structural relationship would help identify the interrelated subjects from a macroscopic view.

Acknowledgement

This work is supported by National Research Foundation of Korea. Grant number: NRF-2012R1A1A3011032.

References

Allen, L., Jones, C., Dolby, K., Lynn, D. and Walport, M., Looking for landmarks: The role of expert review and bibliometric analysis in evaluating scientific publication outputs, *PLoS One*, 4(6):e5910, 2009. doi: 1 0.1371/journal.pone.0005910

Barnes, G.R., Cognitive Processes involved in smooth pursuit eye movements, *Brain and cognition* 68(3), 309-326, 2008.

Bhattacharya, S. and Basu, P., Mapping a research area at the micro level using co-word analysis, *Scientometrics*, 43(3), 359-372, 1998.

Borgatti, S.P., *NetDraw, Graph visualization software*, Harvard: Analytic Technologies, 2002.

Borgatti, S.P., Everett, M.G. and Freeman, L.C., *Ucinet for Windows: Software for social network analysis*, 2002.

Borgatti, S.P., Mehra, A., Brass, D.J. and Labianca, G., Network analysis in the social sciences, *Science,* 323(5916), 892-895, 2009.

Braddick, O. and Atkinson, J., Development of human visual function, *Vision research*, 51(13), 1588-1609, 2011.

Broadus, R.N., Toward a definition of "Bibliometrics", *Scientometrics*, 12(5), 373-379, 1987.

Callon, M., Courtial, J.P., Turner, W.A. and Bauin, S., From translations to problematic networks: An introduction to co-word analysis, *Social science information*, 22(2), 191-235, 1983.

Carrasco, M., Visual Attention, The past 25 years, *Vision research*, 51(13), 1484-1525, 2011.

Cavanagh, P., Visual Cognition, *Vision research*, 51(13), 1538-1551, 2011.

Cronin, B. and Overfelt, K., The scholar's courtesy: A survey of acknowledgement behaviour, *Journal of Documentation*, 50(3), 165-196, 1994.

Deubel, H. and Schneider, W.X., Saccade target selection and object recognition: evidence for a common attentional mechanism.

Vision research, 36(12), 1827-1837, 1996.

Downe-Wamboldt, B., Content Analysis: Method, applications, and issues, *Health care for women international*, 13(3), 313-321, 1992.

Eriksen, C.W. and Schultz, D.W., Information processing in visual search: A Continuous flow conception and experimental results, *Perception & Psychophysics*, 25(4), 249-263, 1979.

Estabrooks, C.A., Winther, C. and Derksen, L., Mapping the field: A bibliometric analysis of the research utilization literature in nursing, *Nursing research*, 53(5), 293-303, 2004.

Freeman, L.C., *The development of social network analysis*, Empirical Press Vancouver, 2004.

Freeman, L.C., A set of measures of centrality based on betweenness, *Sociometry*, 35-41, 1977.

Girvan, M. and Newman, M.E., Community structure in social and biological networks, *Proceedings of the National Academy of Sciences*, 99(12), 7821-7826, 2002.

Guba, E.G. and Lincoln S.Y., Competing paradigms in qualitative research, *Handbook of qualitative research*, 2, 163-194, 1994.

Haythornthwaite, C., Social network analysis, An Approach and technique for the study of information exchange, *Library & Information Science Research*, 18(4), 323-342, 1996.

Hoffman, J.E. and Subramaniam, B., The role of visual attention in saccadic eye movements, *Perception & Psychophysics*, 57(6), 787-795, 1995.

Hood, W. and Wilson, C., The literature of bibliometrics, scientometrics, and informetrics, *Scientometrics*, 52(2), 291-314, 2001.

Kim, G.W., Lim, J.H., Choi, H. and Yun, M.H., Adopting network analysis methods for contextual inquiry: the keyword structure representation of a web behavior, *Proceedings of the HFES Annual Meeting*, 2012.

Koch, C. and Ullman, S., Shifts in selective visual attention: Towards the underlying neural circuitry, *In Matters of Intelligence*, 115-141, Springer, 1987.

Kondracki, N.L., Wellman, N.S. and Amundson, D.R., Content analysis: Review of methods and their applications in nutrition education, *Journal of nutrition education and behavior*, 34(4), 224-230, 2002.

Kowler, E., Eye movements: The past 25 years, *Vision research*, 51(13), 1457-1483, 2011.

Kowler, E., Anderson, E., Dosher, B. and Blaser, E., The role of attention in the programming of saccades, *Vision research*, 35(13), 1897-1916, 1995.

Kretschmer, H. and Aguillo, I., Visibility of collaboration on the web, *Scientometrics*, 61(3), 405-426, 2004.

Mayring, P., Qualitative content analysis, *Paper presented at the Forum qualitative sozialforschung/forum: qualitative social research*, 2000.

Mele, M.L. and Federici, S., A psychotechnological review on eye-tracking systems: Towards user experience, *Disability and Rehabilitation: Assistive Technology*, 7(4), 261-281, 2012.

Morgan, D.L., Qualitative content analysis: a guide to paths not taken, *Qualitative health research*, 3(1), 112, 1993.

O'Regan, J.K., Optimal viewing position in words and the strategy-tactics theory of eye movements in reading, *Eye Movements and Visual Cognition*, 333-354, Springer, 1992.

Opsahl, T., Agneessens, F. and Skvoretz, J., Node centrality in weighted networks: Generalizing degree and shortest paths, *Social Networks*, 32(3), 245-251, 2010.

Otte, E. and Rousseau, R., Social network analysis: A powerful strategy, also for the information sciences, *Journal of information Science*, 28(6), 441-453, 2002.

Owsley, C. and McGwin, G., Vision and driving, *Vision research*, 50(23), 2348-2361, 2010.

Porter, A.L. and Cunningham, S.W., Tech mining, *Competitive Intelligence Magazine*, 8(1), 30-36, 2005.

Price, D.S., A General theory of bibliometric and other cumulative advantage processes, *Journal of the American Society for Information Science*, 27(5), 292-306, 1976.

Pritchard, A., Statistical bibliography or bibliometrics, *Journal of documentation*, 25(4), 348-349, 1969.

Rayner, K., Eye movements and attention in reading, scene perception, and visual search, *The quarterly journal of experimental psychology*, 62(8), 1457-1506, 2009.

Rayner, K., Eye movements in reading and information processing: 20 years of research, *Psychological bulletin*, 124(3), 372, 1998.

Rensink, R.A., Seeing, sensing, and scrutinizing, *Vision research*, 40(10-12), 1469-1487, 2000.

Saka, A. and Igami, M., Mapping modern science using co-citation analysis, *proceedings of the Information Visualization*, 2007.

Rhie, Y.L., Lim, J.H. and Yun, M.H., A Content Analysis of the Trends in Vision Research With Focus on Visual Search, Eye Movement, and Eye Track, *Journal of the Ergonomics Society of Korea*, 33(1), 2014.

Schütz, A.C., Braun, D.I. and Gegenfurtner, K.R., Eye movements and perception: A selective review, *Journal of Vision*, 11(5), 2011.

ScienceDirect, What does "relevance" mean on ScienceDirect?, http://www.info.sciverse.com/documents/files/using/docs/SDrankinginfo.pdf, Accessed February 2013.

Steinman, R.M., Haddad, G.M., Skavenski, A.A. and Wyman, D., Miniature eye movement, *Science,* 181(102), 810-819, 1973.

Wagner, C.S. and Leydesdorff, L., Mapping the Network of Global Science: Comparing international co-authorships from 1990 to 2000, *International Journal of Technology and Globalisation*, 1(2), 185-208, 2005.

Wasserman, S. and Faust, K., *Social network analysis: methods and applications*, 8, Cambridge university press, 1994.

Wolfe, J.M., Inattentional Amnesia Jeremy M. Wolfe, *Fleeting memories: Cognition of brief visual stimuli*, 71, 1999.

Yoon, B. and Park, Y., A text-mining-based patent network: analytical tool for high-technology trend, *The Journal of High Technology Management Research*, 15(1), 37-50, 2004.

Ziegler, B.E., Methods for bibliometric analysis of research: Renewable energy case study, *Massachusetts Institute of Technology*, 2009.

Author listings

Ye Lim Rhie: bsinitsaz@snu.ac.kr
Highest degree: B.S. in Department of Industrial Engineering, Hongik University
Position title: PhD candidate in Department of Industrial Engineering, Seoul National University
Areas of interest: Human Computer Interaction, user research method

Ji Hyoun Lim: smilelim@gmail.com
Highest degree: PhD in the Department of Industrial and Operations Engineering, University of Michigan, Ann Arbor
Position title: Assistant Professor in the School of Design and Human Engineering, UNIST
Areas of interest: Computational Cognitive Modeling, Semantic Network Analysis, and Human Automation Interaction

Myung Hwan Yun: mhy@snu.ac.kr
Highest degree: PhD in industrial and manufacturing engineering from Penn State University
Position title: Professor in the Department of Industrial Engineering at Seoul National University
Areas of interest: Human Factors in Product Design, Perceived Quality, and Affective Product Design

APPENDIX A.

Stimuli	Condition		Measures		Participants	Eye movement behavior	Biological system		Cognitive process	
Visual	Event	Driver fatigue	fMRI	Electrochemical etching	Human	Eye movement	Priming	Working memory	Attention	Top-down control
Vision	Color	Visual servoing	Reaction time	Blink detection	Aging	Saccade	Eye	Hand	Visual attention	Awareness
Pc	Top	Multiple object track	Related potentials	Fission tracks	Schizophrenia	Search	Parietal cortex	Retinal	Modeling	Exploratory search
Mobile visual search	Orientation	Support vector machine	EEG	Eye detection	Autism	Fixation	Visual cortex	Neural network	Spatial attention	Information extraction
Reading	Guided search	Variability	Usability	Kalman filter	Alzheimer's disease	Eye tracking	Inhibition of return	Myopia	Selective attention	Hazard perception
Object	Emotion	Robotics	ERP	Solid statenuclear track detectors	Dyslexia	Feature search	Face	Nystagmus	Visual perception	Consciousness
Web	Crowding	Real time	Visual performance	Psychophysics	Expertise	Motion	Latent inhibition	Retina	Perception	Recognition
Content	Contrast	Eye-head coordination	Observer performance	Human computer interaction	College students	Visual inspection	Rehabilitation	Optokinetic nystagmus	Working memory	Bottom-up
Web search	Training	Culture	Transcranial magnetic stimulation	Face perception	Rehabilitation	Inspection	Posterior parietal cortex	Primate	Object recognition	Attention capture
Feature	Conjunction	Center locating	Computer interaction	Eye tracker	Pain	Gaze	Visual span	Binocul arrivalry	Attentional capture	Prediction
Audio	Bottom	Speed	Action	Single unit recording	Hemianopia	Movement	Depression	Superior-colliculus	Conjunction search	Motion perception
Visual marking	Anxiety		Eye tracking	Safety	Children	Eye movements	Visual field	Frontal eyefields	Grouping	Motor control
Visual short	Feedback		Clustering	Optical coherence tomography	Glaucoma	Visual tracking	Peripheral vision	Cornea	Memory	Latency
Cue	Shape		Reaction time	Neuroimaging	Epilepsy	Sift	Inhibition	Neural network	Saliency	Computational models
Target	Conspicuity		Classification	Face recognition	Parkinson's disease	Saccades	Active vision	Mouse	Learning	Eye movement control
Visualization	Parallel		Stroke	Behavior	PTSD	Smooth pursuit	Vestibulo ocular reflex	Lis	Term memory	Efference copy
Scene perception	Dual		Machine learning	Coordinate systems	Genetics	Saccadic eye movements	Cerebellum	Remote sensing	Based attention	Development
Contextual cueing	Visual acuity		Computer vision	Biomarkers	REMsleep behavior disorder	Eyetracking	Oculomotor	Strabismus	Perceptual learning	Adaptation
Content based image retrieval (CBIR)	Search asymmetry		REM sleep		Nystagmus	Movements	Frontal eye field	Stem cells	Information retrieval	Sensorimotor integration
Image search	Pop		Electro-oculography		Age	Visual search	Superior-colliculus	Serotonin	Signal detection theory	Anticipation

Stimuli	Condition		Measures		Participants	Eye movement behavior	Biological system		Cognitive process	
Visual analytics	Information visualization		EOG		Parasomnia	Vergence	Interstitial nucleusofcajal	Retinal degeneration	Visual memory	Endo-phenotype
Bag of visual words	Line bisection		Eye movement recording		Strabismus	Pursuit	Head		Neglect	Scene perception
Stimuli	Condition		Measures		Participants	Eye movement behavior	Biological system		Cognitive process	
Video search	Motion		Head movements		Stroke	Optokinetic nystagmus	Basalganglia	Psychometric function	Parallel processing	Episodic memory
Image annotation	Visual similarity		Electrical stimulation		Trauma	Rapid eye movement	Vestibular	Photo receptors	Biased competition	Oculomotor control
Visual vocabulary	Ontology		Eyetracking		Amygdala	Antisaccades	Supplementary eyefields	Optokinetic	Cognition	Listing's law
Social media	Driving		REMsleep		Multiple sclerosis	Pursuit eye movements	Prefrontal cortex	Oculometric function	Based image retrieval	Head coordination
Search engine	Navigation		Polysomno-graphy		Sleep disorders	Nystagmus	Tonic neuron	Eye development	Spatial neglect	Hand coordination
Visual processing	Treatment		Emdr		Narcolepsy	Fixations	Otolith	Dry eye	Detection	Eye-hand coordination
Cueing	Priming of popout		REM		Basalganglia	Slow eye movements	Corollary discharge	Area middle temporal	Visual saliency	Motor learning
Video	Pop out		Kinematics		Restless legs syndrome	Vertical eyemovement	Saccadic suppression		Attention capacity	Attention-albias
Opticflow	Sleep		MRI		Individual differences	Exploratory eye movements	Hippocampus		Perceptual span	Cognitive load
Motion-perception	Head movement		Nrem sleep		Visualacuity	Gaze control	Burst		Saliency map	Eye-head coordination
Scene-perception	Convergence		Face detection		Myopia	Eyegaze	Brainstem		Selection	Social cognition
Computer vision	Torsion		HCI		Infancy	Anti-saccade	Ocular		Image retrieval	Active vision
3D	Slow wave sleep		Head movement		Training	Micro saccade	Purkinjecell		Hemispatial neglect	Template matching
Calibration	Accommo-dation		Gaze tracking		Intellectual disability	Track	Multiple sclerosis		Search strategy	Space perception
Cross	Insomnia		Particle filter		Huntington's disease	Eye gaze	Frontal lobe		Visual shortterm memory	Latent tracks
Computer	Sleep deprivation		Face tracking		Allocentric	Object tracking	Extrastriate cortex		Visual working memory	Adaptive optics
Motion perception	Postural control		Visual servoing			Manual tracking	Flocculus		Relevance feedback	Theory of mind
Stereo vision	Problem solving		Camera			Fast track	Stereopsis		Decision making	Motion integration
Stars	Multiple object tracking		Support vector machine			Object track	Binocular vision		Video retrieval	Spiralband model

Stimuli	Condition		Measures		Participants	Eye movement behavior	Biological system		Cognitive process	
Virtual reality	Multi		Oculography			Gaze track	Motor control		Top-down	Speech perception
Image processing	Real		Gaze detection			Opticflow	Oculomotor control		Retrieval	Driver distraction
Imaging	Extra		Time			Occlusion	Neuroophthal-mology		Psychophysics	Deletion syndrome
Active vision	High		Gaze estimation				Vestibuloocular reflex		Multisensory integration	Binocul arrivalry
Driving simulator	Solid		Eye position				Pupil		Implicit learning	
Imaging systems	Oculartorsion		Ion tracks				Dopamine		Feature extraction	
	Monitoring		Etching				Sensorimotor integration		Change detection	
	Long		Electron microscopy				Frontal eyefield		Attentional bias	

APPENDIX B.

	VS1		VS2	
Visual search	Attention	Surface	Reading	Top down
	Object recognition	Priming of pop out	Perceptual span	Rehabilitation
	Emotion	Inhibition of return	Scene perception	Driving
	Spatial neglect	Anxiety	Fixation duration	Hemianopia
	Reaction time	Episodic retrieval	Crowding	Luminance contrast
	Schizophrenia	Human amygdala	Eye movement	1/f noise
	Parallel	Amygdala lesions	Computational model	
	Grouping	Gender	Simulation	
	Executive control	Latent inhibition	Cognitive model	
	Neglect	Schizotypy	Guided search	
	Intertrial priming	Autism	Contrast	
	Visual memory	Model	Visual span	
	Dementia	Signal detection theory	Drivertraining	
	Alzheimer's disease	Selection	Visual world paradigm	
	Visual perception	Dopamine	Working memory	
	Preview benefit	Mental process	Salience	
	Motion	Pop out search	Classification images	

	VS1		**VS2**	
	Facial expression	Dual task interference	Comparative visual search	
	Inhibition	Attentional blink	Bottom up	
	VS3	**VS4**	**VS5**	**VS6**
	Visual attention	Fixation	Selectiveattention	Feature search
	Saccadic selectivity	Saccade	ERP	fMRI
	Search strategy	Human	n2pc	Conjunction search
	Learning	Monkey psychophysics	Neural model	Priming
	Biased competition	Monkey	EEG	Parietal cortex
	Memory	Scanning	Synchrony	Frontal eye field
	Aging	Decision making	Phase locking	Prefrontal cortex
Visual search	Visual short term memory	Control of fixation duration	Gamma band	Binding
	Orientation	Optimalsearch	Attentional capture	
	Popout	Planning	Posteriorn2	
	Categorical perception	Oculomotor	P3	
	Top-down process	**VS7**	**VS8**	**VS9**
	Visual working memory	Psychophysics	Perception	Perceptual learning
	Saliency	Search	Cognition	Conjunctions
	Spatial attention	Spatial uncertainty	Vision	Plasticity
	Expertise	Feature		**VS10**
	Noise	Detection		Color
	Dyslexia	Visual		Uncertainty

	EM1		**EM2**	
	Saccade	Saccadic adaptation	Smooth pursuit	Frontal lobe
	Vision	Remapping	Prediction	Gaze
	Oculomotor control	Visual acuity	Fixation	Eye-head coordination
	Salience map	Oculomotor system	Attention	Perceptual stability
	Children	Video-oculography	Perception	Reaction time
Eye movement	Eyelid	Inhibition	Selection	Gaze saccade
	Visual memory	Decision making	Expectation	Speed perception
	Planning	Motor planning	Anticipation	Retinal image motion
	Development	Saccadic planning	Superior colliculus	Motion perception
	Saccadic suppression	Repeated reading	Head movement	Micro stimulation
	Cognition	Sensorimotor integration	Human	Monkey
	Gaze control	Basalganglia	Prefrontal cortex	Purkinje cell

	EM1		EM2	
Eye movement	Latency	Localization	Cerebellum	Extra retinal signal
	Maintained fixation	Perimetry	Obsessive compulsive disorder	Middle temporal area
	Microsaccade	Optimal search	Corollary discharge	Middle superior temporal area
	Learning	DEMtest	Contrast sensitivity	Adaptation
	Expectations	Pointing	Frontal eyefield	Efference copy
	Hand-eye coordination	Infrared	Oculomotor	fMRI
			Macaque	
	EM3	**EM4**	**EM5**	**EM6**
	REM	Visual attention	Antisaccade	Cat
	Paradoxical sleep	Reading	Schizophrenia	Disjunctive eye movement
	Pgo wave	Visual search	Nicotine	Ocular convergence
	Brainstem	Eye movement control	Endophenotype	Lateral suprasylvian visual cortex
	Lambda response	Word recognition	Family studies	Extrastriate cortex
	REMbursts	Computational model	Exploratory eye movement	Interstitial nucleus of cajal
	Aging	Scene perception	Responsive search score	Vertical eye movement
	Rat	Perceptual span	ADHD	Burst tonic neuron
	Dreaming	Fixation duration	Prosaccade	Anterior ectosylvian sulcus
	P200r	Regressions	Genetics	Neural integrator
	Spectral EEG	Visualspan	Neuropsychology	Lateral suprasylvian area
	Spectral MEG	Movement	Eye movement disturbances	
	Coherent activity	Parafoveal on foveal effect	Relational memory	
	Depression	Hemianopia	**EM7**	**EM8**
	Sleep	Ezreader	OKN	Vergence
	Deprivation	Simulation	Flocculus	Supplementary eye field
	Sleep organization		Vestibuloocularreflex	Disparity
	Picrotoxin		Head-mounted display	
	Locus coeruleus		Infant vision	
	EM7	**EM10**	**EM11**	**EM12**
	EMDR	Motion	Motor control	Convergence
	Working memory	Depth	Vergence eye movement	Divergence
	PTSD	Opticflow	Hand movement	
	Auto-biographical memory	Heading	Eye-hand coordination	
	EM13	EM14	EM15	

	EM7	EM10	EM11	EM12
Eye movement	Eye track	Memory	Electrical stimulation	
	EEG	Amnesia	EOG	
	Artifact removal			

	ET1	ET2		ET3
Eye track	Smooth pursuit	Perception	Pursuit	Vestibulo-ocular reflex
	Psychometric function	Motion	Working memory	Video oculography
	Oculometric function	Track	Children	Vestibular
	Middle temporal area	Eye movement	Oculomotor	3D
	Oculo-manual track	Attention	Visual search	Eye position
	Coordination control	Human	Head movement	UV
	Schizophrenia	Prediction	Fixation	Fluorescent
	Motion perception	Gaze	Extra retinal	**ET4**
	Vergence	Development	Eye-head coordination	Cerebellum
	Genetics	Saccade	Supplementary eye field	Purkinjecell
	Micro stimulation	Frontal eye field	Parietal cortex	**ET5**
	Adaptation	Lateral intraparietal cortex	Memory	Cat
	Anti-saccade	Superior colliculus	Multiple object track	Extrastriate cortex
	Monkey	Visual attention		Lateral suprasylvian area
	OKN	Reading		Ocular convergence