



## Aslib Journal of Information Management

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### Article information:

To cite this document:

Maayan Zhitomirsky-Geffet Judit Bar-Ilan Mark Levene , (2016), "Testing the stability of "wisdom of crowds" judgments of search results over time and their similarity with the search engine rankings", Aslib Journal of Information Management, Vol. 68 Iss 4 pp. 407 - 427

Permanent link to this document:

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# Testing the stability of “wisdom of crowds” judgments of search results over time and their similarity with the search engine rankings

Search engine rankings

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## Abstract

**Purpose** – One of the under-explored aspects in the process of user information seeking behaviour is influence of time on relevance evaluation. It has been shown in previous studies that individual users might change their assessment of search results over time. It is also known that aggregated judgements of multiple individual users can lead to correct and reliable decisions; this phenomenon is known as the “wisdom of crowds”. The purpose of this paper is to examine whether aggregated judgements will be more stable and thus more reliable over time than individual user judgements.

**Design/methodology/approach** – In this study two simple measures are proposed to calculate the aggregated judgements of search results and compare their reliability and stability to individual user judgements. In addition, the aggregated “wisdom of crowds” judgements were used as a means to compare the differences between human assessments of search results and search engine’s rankings. A large-scale user study was conducted with 87 participants who evaluated two different queries and four diverse result sets twice, with an interval of two months. Two types of judgements were considered in this study: relevance on a four-point scale, and ranking on a ten-point scale without ties.

**Findings** – It was found that aggregated judgements are much more stable than individual user judgements, yet they are quite different from search engine rankings.

**Practical implications** – The proposed “wisdom of crowds”-based approach provides a reliable reference point for the evaluation of search engines. This is also important for exploring the need of personalisation and adapting search engine’s ranking over time to changes in users preferences.

**Originality/value** – This is a first study that applies the notion of “wisdom of crowds” to examine an under-explored in the literature phenomenon of “change in time” in user evaluation of relevance.

**Keywords** Ranking, Change in time, Wisdom of crowds, Relevance judgement

**Paper type** Research paper

## 1. Introduction

Numerous general models of information seeking and web searching behaviour have been proposed in the past such as Ellis (1989), Bates (1989), Kuhlthau (1991), Dervin (1992), Johnson and Meischke (1993), Marchionini (1995), Spink (1997), Wilson (1999), Fisher *et al.* (2005), Knight and Spink (2008), Du and Spink (2011) and Case (2012). Relevance is a central notion in information science and is an important part of user information seeking models (Saracevic, 2007). This study investigates an under-explored topic in the literature (Saracevic, 2007): stability and change of user assessment of search



results over time. Human evaluation of documents relevance is a complex process that requires coordination of multiple cognitive tasks (Du and Spink, 2011). User result evaluation is needed in many fields and has many purposes, hence it is important to understand the factors and phenomena behind it. This study aims to extend the understanding of the result evaluation component of the proposed web search behaviour models, with respect to the temporal change factor. In this broad context, this research contributes to modelling the change in user relevance evaluation behaviour over time.

As stated by (Saracevic, 2007, p. 2139): “The role of research is to make relevance complexity more comprehensible formally and possibly even more predictable”. Accurate ranking of search results according to the users’ preferences is one of the most important challenges of the modern search systems. However, previous research found a low correlation between users’ and search engines’ rankings of search results (Vaughan, 2004; Veronis, 2006; Bar-Ilan *et al.*, 2007; Lewandowski, 2008; Bar-Ilan and Levene, 2011), thus, leading to a conclusion that more work is required to improve the systems’ ability to assess documents’ relevance.

Previous work above and those reviewed in Saracevic (2007) concentrated on the successive or evolving search processes, where further iterations are used to refine and improve the search. It is known that users’ information needs, evaluation criteria and preference of results, as well as query formulation and retrieved result sets tend to change during the search process, since users better understand their needs at the end of the process rather than at the beginning, and try to refine their search to get the optimal results. As opposed to the above works investigating an evolution of search and result evaluation process, this study explores a different dimension of change in user evaluation of relevance: the “change in time”. This change, if it exists, reflects the essential subjectivity and instability of user perception and evaluation of relevance, and thus might reveal the inherent complexity, subjectivity and vagueness/fuzziness in users’ perception of relevance. This type of change might be discovered when other factors of influence are neutralised (i.e. in independent evaluation sessions with identical tasks, environments, goals and data but at two different points in time). In other words, if users were asked to choose a relevance grade or a rank for each result, given the same query and result set, would these assessments remain stable over time? Would users provide similar relevance judgements and ranks to the same results and queries in a few weeks or months?

It was shown in previous work (Scholer *et al.*, 2011) that individual users might change their assessments of search results over time due to subjectivity in human relevance perception or even human error. Inter-user agreement on ranking of search results has also been shown to be quite low due to subjectivity in human judgements (Bar-Ilan *et al.*, 2007; Bar-Ilan and Levene, 2011). On the other hand, it is also known that in many fields of knowledge aggregated judgements of multiple individual users lead to more correct and reliable decisions; this phenomenon is called “wisdom of crowds” (Cooper *et al.*, 2010; Giles, 2005; Surowiecki, 2005; Preis *et al.*, 2013; Harshavardhan *et al.*, 2013; Bollen and Mao, 2011; Mortensen *et al.*, 2015; Zhitomirsky-Geffet and Erez, 2014; Cen *et al.*, 2009; Bao *et al.*, 2007). Therefore, this study’s research goal is to examine the level of change and stability of aggregated judgements compared to individual user judgements. Accordingly, the two main research questions tested in this study are:

- RQ1. Whether and how aggregated judgements will be more stable and thus more reliable over time than individual user judgements?
- RQ2. Whether and to what extent are the search engines’ ranking similar/different from the “wisdom of crowds” ranking?

As noted above, previous research reveals quite a high level of disagreement between the ranking of search engines and rankings produced by individual. In this context an additional goal of this study is to examine to what extent the aggregated “wisdom of crowds” judgements differ from the ranking of search engines.

The rest of this paper is organised as follows. In the next section the related work is reviewed. Then our study setup is described, and following that the results are presented and discussed. Finally, some conclusions and future research directions are provided.

## 2. Related work

First, a review of some previous studies is presented, which apply “wisdom of crowds”-based techniques to improve and learn search result relevance and ranking. Then, the most relevant user studies are reviewed, which are related to agreement on ranking and relevance judgements and comparison between user and search engine ranking.

### 2.1 “Wisdom of crowds” techniques and information retrieval

In recent years, a number of articles have suggested using social tags as a source of “wisdom of crowds” for improving ranking of search results (e.g. Yanbe *et al.*, 2007; Bao *et al.*, 2007; Liu *et al.*, 2009; Choochaiwattana and Spring, 2009; Zhitomirsky-Geffet and Daya, 2015). Yanbe *et al.* (2007) suggested enhancing result ranking by integrating the PageRank algorithm with the tag information on social bookmarking sites. Bao *et al.* (2007) devised two algorithms for ranking according to social bookmarking: first, the SocialSimRank algorithm which assesses the resemblance between the query and the tags; and second, the SocialPageRank algorithm which measures the quality of a page according to its popularity. Their study indicates that these two algorithms significantly improved the quality of result ranking. A similar method was presented in an additional study (Liu *et al.*, 2009). This method ranks search results according to a query’s resemblance to the tags, with the rank weight determined by the popularity of the tags. Another study (Choochaiwattana and Spring, 2009) considered the number of social tags that matched the query terms. The authors reported that the ranking method that yielded the best results, ranked the document according to the number of users who tagged it on Delicious with tags that matched the terms of the search query. Kawase *et al.* (2014) employed Wikipedia categories constructed by wisdom of crowds as a basis for fingerprints creation for different web services (e.g. Twitter, Flickr, Delicious). The topic coverage of these services’ represented by their fingerprints was comparatively analysed. These fingerprints were also shown to be effectively used for a movie recommendation task in the crowdsourcing experiment. Singh *et al.* (2013) developed an eBook recommender system based on content analysis and various social web eResources, e.g. YouTube, Slidershare, Twitter and LinkedIn. Zhitomirsky-Geffet and Daya (2015) presented a technique for using social tags to extract diverse subtopics for a query, and reduction and re-ranking of search results, according to the most prominent and discriminative subtopics.

Another group of investigations used user click-through data as a source of “wisdom of crowds” to infer user relevance preferences of search results (Cen *et al.*, 2009; Agichtein *et al.*, 2006; Dou *et al.*, 2008). Cen *et al.* (2009) showed that it is possible to accurately evaluate relevance of search results based on aggregated click-through information from query logs. The underlying assumption was that a result with a larger amount of clicks is more relevant to the query than a result with fewer clicks. Agichtein *et al.* (2006) proposed an idea of aggregating information from many

unreliable user search sessions, instead of treating each user as a reliable expert to predict user relevance assessment of search results. Dou *et al.* (2008) used aggregate click-through logs to learn the ranking of search results, and found that the aggregation of a large number of user clicks is indicative of relevance preferences. Harris (2014) found that crowds are able to predict the consensus ranking of search results with significantly higher recall when asked to judge document relevance based on their estimate of the consensus decision than when the judgement is based on their personal viewpoint. Zhitomirsky-Geffet *et al.* (2016) applied a similar methodology for classification of diet ontology's statements by crowdsourcing. They found that crowds are able to correctly distinguish between consensual and controversial statements when asked to predict the experts' opinion.

In summary, the above studies demonstrated that "wisdom of crowds"-based techniques applied to various types of user data can increase the reliability of this data for learning relevance preferences and ranking of search results. The goal of the current study is to test whether such techniques of aggregation of user-produced data might increase the stability of user evaluation of search results over time.

### 2.2 Relevance evaluation and ranking of search results by users and search engines

Lewandowski (2008) conducted a user study with 40 subjects who judged relevance (on a binary scale) of top-20 results of five search engines. He reported quite low precision at 20 results, ranging from 0.37 to 0.52, while Yahoo! and Google outperformed the other search engines and yielded quite similar results. Vaughan (2004) compared 24 subjects' ranking of four queries' results with those of Google, AltaVista and Teoma. In his study, Google outperformed the other search engines with 0.72 average correlation between Google's and subjects' rankings. Veronis (2006) conducted a user study with 14 students as subjects who judged the relevance of top-10 results of six search engines on 14 topics and five queries per topic. He found that Google and Yahoo! significantly outperformed the other search engines but still reached only an average score of 2.3 on a 0-5 relevance scale. A later study examined differences in relevance judgements of results retrieved by Google, Yahoo!, Bing, Yahoo! Kids and ask Kids search engines for 30 queries formulated by children (Bilal, 2012). Yahoo! and Bing produced a similar percentage in hit overlap with Google (nearly 30 per cent), while Google performed best on natural language queries, and Bing showed a similar precision score ( $p = 0.69$ ) on two-word queries. In a recent large-scale study (Lewandowski, 2015) a sample of 1,000 informational and 1,000 navigational queries from a major German search engine was used to compare Google's and Bing's search results. It was found that Google slightly outperformed Bing for informational queries, however, there was a substantial difference between Google and Bing for navigational queries. Google found the correct answer in 95.3 per cent of cases, whereas Bing only found the correct answer 76.6 per cent of the time. These studies did not consider ranking of the results but only compared their relevance grades.

A few studies compared user ranking of search results to popular search engines' ranking. In a study (Bar-Ilan *et al.*, 2007) users were presented with randomly ordered result sets retrieved from Google, Yahoo! and MSN (now Bing) and were asked to choose and rank the top-10 results. The findings, generally, showed low similarity between the users and the search engines rankings. In a follow-up study (Bar-Ilan and Levene, 2011), country-specific search results were tested in a similar way. In this case it was shown that at least for Google, the users preferred the results and the rankings of the local Google version over other versions. In Hariri (2011) the authors also studied

Google rankings and asked whether top results are considered more relevant by the users. In this study the fifth ranked result was judged to be of highest relevance, slightly more than the top ranked result. These studies only asked the users to rank the results, without asking for their relevance judgements.

### 2.3 Change in time in relevance and ranking evaluation

Saracevic (2007) in his extensive review on relevance discusses the dynamics of relevance evaluation over time, when the information need changes due to information gained during the information search. One of the first studies of dynamic changes was carried out by Rees and Schultz (1967). According to the information retrieval model of Bates (1989) during the iterative process of search the user relevance judgements of the results are influenced by the results of previous search. Later, Spink and Dee (2007) defined a web search model as comprising multiple tasks and cognitive shifts between tasks (e.g. shifts between topic, result evaluation, document, information problem, search strategy). Cognitive shift was defined as a human ability to handle the demands of complex and often multiple tasks resulting from changes due to external forces. Du and Spink (2011) found that evaluation is one of the three most experienced states during multi-tasking search process. Also shifts from one evaluation to another were quite frequent among other shift types. Saracevic (2007) mentions additional studies where the relevance assessments at different points in the information seeking task of more than two participants were investigated (Smithson, 1994; Bruce, 1994; Wang and White, 1995; Bateman, 1998; Vakkari and Hakala, 2000; Vakkari, 2001; Tang and Solomon, 2001). However, the setting of the above mentioned studies is different from the current setting. In the previous studies the users' information need changed as the task evolved. In the current study the participants were explicitly instructed to use the same criteria and goals, the same query and result sets in both rounds of the experiment. The question is what happens in two separate standalone search sessions when the task is identical, and assessed at two different points in time? The only difference between the sessions is that the users saw the given set of documents (or their snippets) once before.

Self-agreement and change in user evaluation of the same search results for the same query is an under-explored area. Scholer *et al.* (2011) studied repeated relevance judgements of TREC evaluators. They found that quite often (for 15-24 per cent of the documents) the evaluators were not consistent in their decisions, and considered these inconsistencies to be errors made by the assessors. As opposed to their study, here changes in (ordinary) users' rather than domain experts' judgements are measured, for relevance on a four point-scale as opposed to the binary scale used by them, and also for ranking of the top-ten results.

Scholer *et al.* (2013) studied the influence of exposure to more or less relevant documents on relevance assessment of documents shown later. They asked their users to evaluate the relevance (on a four-point scale) 28 documents, where the first three and the last three were identical, thus they saw the same documents for the second time after viewing and judging 25 other documents. In their study the users viewed documents for the second time within the same sessions, while in our study there is a significant gap in time between the two assessments. The reported self-agreement on these three documents was only about 50 per cent. To the best of our knowledge changes in users' rankings over time have not been examined in any previous research.

In summary, it has been shown in the literature that there is a substantial difference between users' and search engines' relevance evaluation of search results. This means that in order to reduce this gap more research is needed into this field. The main

differences between the current research and the reviewed literature are as follows. Studies that explored the change in users' search behaviour over time, mostly addressed successive search behaviour and used only one type of evaluation (either ranking or relevance judgement). Neither of them investigated the "wisdom of crowds" evaluation change in time. Conversely, past works that applied "wisdom of crowds" techniques did not explore the temporal factor of information retrieval and evaluation. The most related study by Scholer *et al.* (2011) used only binary evaluation of documents' relevance and did not check the change in "wisdom of crowds" result evaluation.

### 3. Method

#### 3.1 Study setting

**3.1.1 Queries.** Ideally users choose topics of their interest to search for and make assessments, however when the queries differ between users their judgements cannot be aggregated. Therefore, to test the above research questions two popular scientific topics were selected as queries by the authors, BigData (in English) and Alzheimer (in Hebrew). In addition to the queries a search scenario was provided as "for the aim of preparing a summary of the topic, based solely on the results in this set" (they did not actually have to submit the summary).

The query topics were not part of the curriculum, and were not studied either in this course or in any other courses the participants took. For each query two separate sets of 20 search results were created. The search results of the first set were collected from Google and Bing, and included top-10 Google and top-10 Bing, supplemented, because of the partial overlap between the top results of the two search engines. The second set comprised the Google results displayed on the first and the tenth result pages (i.e. results 1-10 and 101-110). Thus, four different tasks were defined each with a different query and a different result set for each query: AlzheimerGoogle10&100, BigDataGoogle10&100, AlzheimerGoogle&Bing and BigDataGoogle&Bing. Google and Bing are the two leading search engines according to comScore (2015), and this is why we chose to present results from these search engines.

**3.1.2 Participants.** Two randomly created groups of 42 and 45 information science students, who participated in the "Introduction to Information Science" course, were asked to judge the results. No specific demographic data were collected for the purpose of this study. Each group was presented with two out of the above four tasks, one for each query. Every result set was judged by only one of the groups. The order of presentation of the results to the students was random, to avoid prior bias in their judgements. The students were instructed to judge the results in the set with respect to the query with the aim of preparing a summary of the topic, based solely on the results in this set (they did not actually have to submit the summary). Two types of judgements were featured: relevance judgements on a scale of four: not relevant (1), slightly relevant (2), somewhat relevant (3) and relevant (4), where ties were allowed; ranks for the top-10 out of 20 results with no ties allowed. The tasks with queries and results for judgement were presented to the participants in Google forms and included title, URL and snippet as displayed by the search engine for each result along with two types of judgement scales.

Two months later the same participants were asked to judge the same result sets for the same queries with the same evaluation criteria and instructions but presented in a different random order. This time the same set of results was presented in a different random order to prevent the students from copying or fully recalling their first

judgements. We note that the first round of evaluation took place about six weeks after the fall semester started, and the second time occurred at the end of the fall semester.

The participants filled-in the Google forms using their personal computers (laptops or desktops) for both rounds. Most of them performed judged the relevance and ranked both queries on the same day in the round, although this was not a requirement.

*3.1.3 Relevance judgement and engines' rankings.* The two types of judgements were employed, since they test different cognitive processes executed by the users and we wanted to understand the differences between them. When assessing relevance of a document to a query, this can be done independently from the other retrieved documents and thus requires a smaller amount of cognitive shifts and their coordination, while for ranking the whole set of retrieved documents must be taken into account engaging a higher level of multi-tasking and coordinated cognitive shifts. The choice of the relevance scale was based on our preliminary experiment, where we asked 27 users to decide on the number of relevance categories and then assign each search result to a category. The average number of categories was 4.1, which led us to the decision in these experiments to use a four-point scale for relevance. It seems more reasonable to ask the participants rank only top-10 results than all 20, as it would require too much cognitive effort, coordination of multiple cognitive shifts (Du and Spink, 2011), and time to compare and uniquely rank 20 results of two different queries. Also search engines normally present only the top-10 results on the first page, which are considered to be the most important for users (Jansen and Spink, 2006; Chitika, 2013, p. 5).

### 3.2 Presentation bias

In each round all the participants in a given group saw the results in the same order. While, in general, the order of results might have influenced the judgements (Bar-Ilan *et al.*, 2009; Joachims *et al.*, 2007), it has been shown that when the number of results is small than this influence is insignificant (Saracevic, 2007). Interestingly, Table I shows that in all cases users changed their minds about the rankings. However, as also shown in Table I, for three out of the four tasks there was no noticeable correspondence between the order of the results' presentation to the users and their ranks. Only for the AlzheimerGoogle&Bing task two of the first three displayed results were ranked at top-3 ranks by the users. This can be explained by the fact that in comparison to the other three tasks, for this task there were substantially less non-relevant results, with relevance value of 1 (by 53-123 per cent in the first round of the experiment, on average over all the users, and by 15-113 per cent on average for the second round). Also, for the AlzheimerGoogle&Bing task the percentage of relevant results (with the relevance grade of 4) is substantially higher than for the other tasks (by 10-13 per cent, on

Displayed to users as	BigDataGoogle&Bing		BigDataGoogle10&100		AlzheimerGoogle&Bing		AlzheimerGoogle10&100	
	Ranked in Round 1 as	Ranked in Round 2 as	Ranked in Round 1 as	Ranked in Round 2 as	Ranked in Round 1 as	Ranked in Round 2 as	Ranked in Round 1 as	Ranked in Round 2 as
1	13 (5, n/a)	5 (4, n/a)	20 (6)	6 (3)	3 (7, 7)	2 (4, 3)	8 (101)	20 (106)
2	3 (8, n/a)	11 (7, n/a)	14 (105)	8 (110)	2 (n/a, 10)	6 (n/a, 12)	2 (6)	14 (102)
3	7 (6, n/a)	14 (5, n/a)	16 (106)	9 (10)	15 (10, n/a)	3 (n/a, 8)	14 (109)	11 (105)

**Note:** The corresponding search engines' ranks of these results are displayed in parentheses (Google rank, Bing rank where available), if not available it is denoted as n/a

**Table I.**  
The average ranks of the first three results displayed to the users at each of the rounds for every query



average for the first round, and by 15-24 per cent, on average for the second round). The differences between the percentages of the most relevant and the least relevant results for every task and round are presented in Figures 1 and 2.

The participants were informed that their rankings will be aggregated and analysed anonymously, and those who wished not to contribute their data to the aggregated study were asked to inform the course instructor by e-mail. No students asked to withdraw their data. Although the experiments involve human subjects (students), no personal information was gathered on them. The Faculty of Humanities' IRB (ethics committee) waived the need for written consent. The IRB of the Faculty of Humanities in Bar-Ilan University approved the experiments.

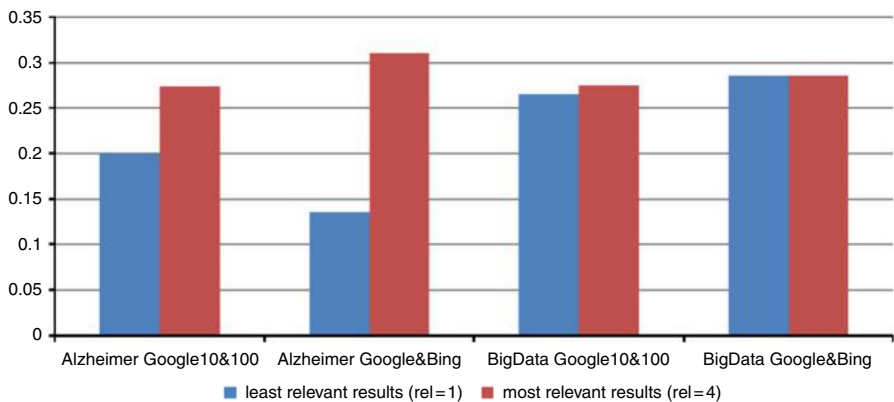
### 3.3 Measures of change in user evaluation of search results

To test these research questions, two measures were proposed to calculate the aggregated judgements of search results that reflect the "wisdom of crowds" of a user group and compare their stability to the individual user judgements. Two types of judgements were considered in this study: relevance on a four-point scale with possible ties, and ranking on a ten-point scale without ties.

To compute the aggregated "wisdom of crowds" ranking and relevance-based ranking grades, all the individual users' values for every result were summed and the

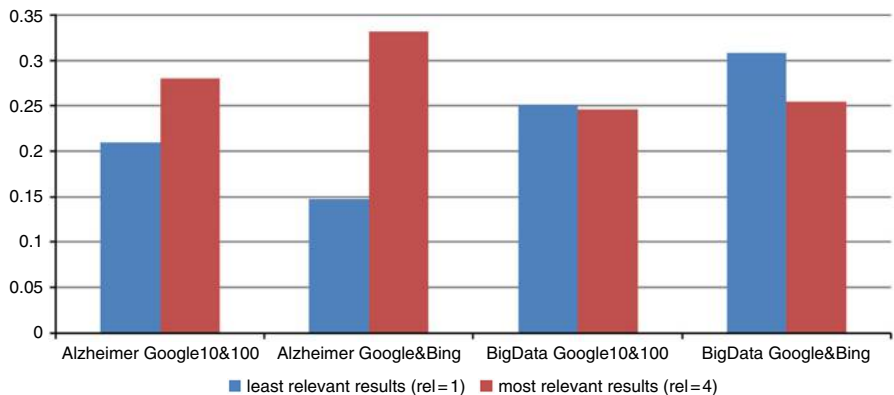
**Figure 1.**

The averaged (on all the users) percentage of the results judged as least and most relevant for every task for the first round of the experiment



**Figure 2.**

The averaged (on all the users) percentage of the results judged as least and most relevant for every task for the second round of the experiment



result list was sorted by these sums in ascending order to obtain the ranked list of results by users' ranking, and in descending order to obtain the list of results by users' relevance judgements. This was repeated for both rounds of the experiment. These aggregated results are referred to as consensus ranking-based ranking and consensus relevance-based ranking. In this study there were no ties (i.e. two items with exactly the same aggregate score). In case there are ties, these are resolved randomly.

To assess the stability of the judgements over time for each individual user and of the user consensus, two measures were devised. For each query and result set, the proportion of the results in the set that was not given identical ranks or relevance judgements by a specified user or by the user consensus, on the first and second rounds of the study was calculated. This measures the amount of change at the exact match level (i.e. results with distance 0 are those that were identically judged by the given user in both rounds). Further, cases when the rankings or relevance judgements were not precisely identical in both rounds but still sufficiently close were also considered.

Formally, the change coefficient at a distance  $d$ , with  $0 \leq d \leq |S|$  is defined for a given set of results,  $s_1, s_2, \dots, s_k$ , evaluated twice by a user (or by the user consensus),  $u$ , either with ranking or relevance values,  $r_1$  and  $r_2$ , as follows:

$$\Omega(d) = 1 - \frac{\sum_{i=1}^{|S|} n(s_i)}{|S|}, \text{ where } n(s_i) = \begin{cases} 1, & |r_1(s_i) - r_2(s_i)| \leq d \\ 0, & \text{otherwise} \end{cases}$$

Thus,  $\Omega(d)$  is the proportion of the results that are judged in the two rounds at distance greater than  $d$  in the set  $S$ . Note that for  $d=0$  the change coefficient reduces to the exact match case, while  $d > 0$  defines the more general case. For relevance all the 20 results in  $S$  were judged by the users and thus all of them are considered in the calculation of the change coefficient. However, for ranking only the top-10 results were actually assessed by the users. Therefore, for ranking only, as there are more results than ranks, the unranked results are technically assigned the rank of 11. Only results with at least one of the ranks being lower than 11 are considered. This is because results that were assigned rank 11 were not actually ranked by the users.

In addition, based on subsets of  $k$  ranks, the proportion of new non-overlapping results in the subset of  $k$  consecutive ranks is measured, which starts at a position  $p$ , that were introduced in the second round of the study. More formally, given a set of results  $R$ , and a consecutive subset of ranks  $(r_p, r_{p+1}, \dots, r_{p+k})$  where  $1 < r_i \leq |R|$ , two subsets of ranked results are constructed with the corresponding ranks for each of the two rounds,  $R_1$  and  $R_2$ . Thus, the change in  $k$ -subset measure, is defined as follows:

$$NO(p, k) = 1 - |R_1 \cap R_2|/k, \text{ for some } p, k = \{1 \dots N\}$$

In the sequel  $NO(\text{top-}k)$  will stand for  $NO(1, k)$  and  $NO(\text{last-}k)$  will stand for  $NO(N-k+1, k)$ . This measure computes the proportion of results in a certain subset in one of the rounds that were not part of this subset in the other round.

#### 4. Results and discussion

To answer the first research question of this study we computed the changes in the individual users' judgements and the corresponding changes in the consensus judgements by the two types of measures defined above and then compared these changes. It was found that the majority of changes in user evaluation of search results are local within 1-2 close ranks and relevance values. Moreover, the consensus rankings

(obtained by aggregation of the individual ranks) were considerably more stable (changed in time less) than the individual users' rankings, but were still quite different (by 30-60 per cent) from the search engine's rankings. These findings imply that "wisdom of crowds" decreases the subjectivity and increases the stability of user ranking and thus can be used as a reliable reference for user relevance evaluation behaviour modelling.

4.1 Analysis of the change coefficient for individual user judgements vs consensus judgements

To this end, first, the changes of individual users' rankings and relevance judgements for the same 20 results between the first and second rounds of the experiment were computed. To this end, the average of the change coefficients,  $\Omega(d)$ , with  $d=0$  over the individual users' rankings and relevance judgements were calculated. The results for different studies are presented in Table II. Then, the change coefficient was measured for distances greater than or equal to one between judgements in the two rounds. In our experiment  $d=1$  for relevance, and  $1 \leq d \leq 3$  for rankings were used (as the distance between judgements of the results in the two rounds), and are also presented in Table II. For  $\Omega(d > 1)$  only changes of distance 2 or more were counted (i.e. if e.g., an item was ranked seventh in the first round, and ninth or above, or fifth or below in the second round, then we consider it as a change). As mentioned above, all unranked items by the user received a virtual rank of 11.

It can be observed that, in general, similarly high values (84-87 per cent for ranking and 43-53 per cent for relevance) were obtained for the different queries and result sets, recalling that when  $\Omega(d) = 0$  then no change occurred. Further, the explored research question is whether consensus ranking, which aggregates all the individual ranks for a given result into a single score, would exhibit a smaller amount of changes than the average for individual users. To test this question, each result for every query is assigned an identifying number. Then, the consensus rank/relevance score for every result of each query and result set is computed as a sum of all its individual user ranks/relevance grades, similar to the "agreed" ranking defined by Bar-Ilan *et al.* (2007). Then, all the results with a consensus rank higher than 10 were assigned a rank value of 11 as was done for the individual rankings, since in our experiments users could only rank the best 10 out 20 results. According to the definition of  $\Omega(0)$  and similarly to the analysis of the individual user judgements the change coefficients for the consensus ranking is calculated over the top-10 results only. The same method was applied to compute the consensus relevance grades for relevance-based ranking but all 20 results were assigned a rank in this case. Thus, the consensus relevance-based ranking shows a way to create a ranking for the full result list without the users ranking them explicitly. The results of the change coefficient measure for the consensus ranking and relevance-based ranking are displayed in Table III.

**Table II.**  
The average change coefficient values of individual users for ranking and relevance with different distances and result sets

Experiment	Ranking				Relevance	
	$\Omega(0)$	$\Omega(1)$	$\Omega(2)$	$\Omega(3)$	$\Omega(0)$	$\Omega(1)$
AlzheimerGoogle10&100	0.87 (0.18)	0.61 (0.23)	0.45 (0.22)	0.33 (0.19)	0.48 (0.11)	0.12 (0.07)
AlzheimerGoogle&Bing	0.87 (0.18)	0.67 (0.21)	0.50 (0.20)	0.39 (0.17)	0.53 (0.09)	0.15 (0.05)
BigDataGoogle10&100	0.84 (0.18)	0.62 (0.22)	0.44 (0.20)	0.31 (0.17)	0.52 (0.14)	0.13 (0.06)
BigDataGoogle&Bing	0.87 (0.18)	0.64 (0.21)	0.48 (0.20)	0.32 (0.17)	0.43 (0.15)	0.10 (0.06)
Average of the averages	0.86 (0.18)	0.64 (0.22)	0.47 (0.20)	0.34 (0.17)	0.49 (0.12)	0.13 (0.06)

**Note:** Standard deviation values are shown in parentheses following the average

The change coefficient for relevancies is considerably lower than for rankings (in Table II), which may indicate that for users, ranking is generally more difficult than judging relevance. As expected, a consistent decrease in the change coefficient is observed, especially the considerable decrease between distance 0 and distance 1, for the relevance judgements, which indicates that most of the changes in relevance judgements were local within distance 1. Also, for ranking the majority of changes were local within distance 2. In addition, virtually similar numbers for both queries and result sets were obtained. This reflects a general pattern in user evaluation behaviour which is not specific to a specific case, users or data set.

Here we introduced new measures and a unique experimental setting, aiming to examine the time as the only varying parameter. The only closely related works for comparison are those by Scholer *et al.* (2011, 2013), which we mentioned earlier in the related work section. Our results on change in relevance with  $d=0$  seem quite similar to those of (Scholer *et al.*, 2013) who reported about 50 per cent change rate. When considering  $d=1$  as an approximation of the two-point scale, our results (12-15 per cent change coefficients) are also comparable but slightly lower to those of (Scholer *et al.*, 2011), who reported on 15-24 per cent change rates. However, as opposed to our approach, Scholer *et al.* (2011) viewed cases where the document was evaluated differently the second time as errors. In the experimental setting of (Scholer *et al.*, 2013), three documents were assessed twice within a short period of time (of about one hour) and the results in this study were not interpreted.

The results for consensus ranking and relevance-based ranking are quite similar despite the fact that the former was calculated for top-10 results only, while the latter considers all 20 results. For ranking with  $d=0$  (exact match) were obtained, while for  $d>0$  the numbers are strictly monotonically decreasing (except for AlzheimerGoogle&Bing task for  $\Omega(2)$  and  $\Omega(3)$ ). As can be observed by comparing the first four columns of Tables II and III, the numbers in Table III are 22 per cent lower on average, for the averaged individual ranking change coefficient for the exact match, and 51 per cent lower on average for  $d>1$ , than the corresponding values, shown in Table II. The smallest decrease in change (of 8 per cent) was observed for AlzheimerGoogle&Bing task ( $d=0$ ), and the greatest decrease (of 84 per cent) was observed for the consensus ranking of the BigDataGoogle&Bing task ( $d=1$ ). The change coefficient for consensus ranking is more than one standard deviation lower than the average mean change coefficient for the individual users.

#### 4.2 Analysis of the change in the subsets of $k$ ranks for individual user judgements vs consensus judgements

Next, our second measure was applied to compute the change in the subsets of  $k$  ranks. Table IV considers the change in the top-5, last-5 and unranked results. Thus, the

Experiment	Ranking-based ranking				Relevance-based ranking				Table III. The change coefficient for consensus ranking and relevance grades with various distances for different experiments
	$\Omega(0)$	$\Omega(1)$	$\Omega(2)$	$\Omega(3)$	$\Omega(0)$	$\Omega(1)$	$\Omega(2)$	$\Omega(3)$	
AlzheimerGoogle10&100	0.70	0.40	0.20	0.10	0.70	0.40	0.20	0.10	
AlzheimerGoogle&Bing	0.80	0.60	0.40	0.40	0.85	0.50	0.50	0.40	
BigDataGoogle10&100	0.60	0.30	0.10	0.10	0.70	0.40	0.20	0.10	
BigDataGoogle&Bing	0.60	0.10	0.10	0.10	0.65	0.25	0.00	0.00	
Average	0.68 (0.10)	0.35 (0.21)	0.20 (0.15)	0.18 (0.15)	0.73 (0.09)	0.39 (0.11)	0.23 (0.21)	0.15 (0.18)	

non-local (inter-subset) changes were measured between the two evaluation rounds in the top-5 result subset, (i.e. NO(top-5)), and in the last-5 result subset, (i.e. NO(last-5)), and in all the unranked results, (i.e. NO(unranked)), results that were unranked at least in one of the rounds, as a third subset of ranks.

We note that for all the tasks there is much more change in the middle category subset of results (last-5) than in either the top ranked most relevant category (top-5) or the unranked least relevant subset. A reasonable explanation for this is that it is probably easier for the users to judge the extremes than the middle-category results. The most stable category was “unranked results” for which over two thirds of the results remained unranked in both rounds. For the top-5 results the majority remained in top-5 over both rounds.

The NO( $p, k$ ) values for the consensus ranking-based ranking also decreased in comparison to the individual user ranking as shown in Table V and compared to Table IV. The obtained results show less change in the top- $k$  values for the top-5 consensus ranking (10 per cent average NO(top-5)) than for the last-5 (30 per cent average NO(last-5)). Moreover, there were lower changes except for the AlzheimerGoogle&Bing task in the top-5 and last-5 categories for the consensus ranking than for the individual user rankings in the top-5 results (where 42 per cent of results were new in the second round on average for all the experiments). In particular, it was found that except for the AlzheimerGoogle&Bing task, there were no new results within the top-5 results in the consensus rankings between the rounds; however, there are some changes in the actual rankings. Similarly, only one out of the top-10 results (10 per cent) of the consensus ranking was different for the first and second rounds for all the experiments (compared to 27 per cent on average for individual users’ ranking in Table IV). Again, as for the change coefficient above, the change in subsets of  $k$  ranks for consensus ranking is more than one standard deviation lower than the average mean change for the individual users.

Thus, the consensus ranking which reflects the “wisdom of crowds” evaluation is more stable than individual user rankings. Within distance 2 about 80 per cent of

**Table IV.**  
The change in ranking for unranked, top-5 and last 5 for the different experiments

	NO(unranked)	NO(last-5)	NO(top-5)
AlzheimerGoogle10&100	0.30 (0.16)	0.64 (0.28)	0.41 (0.20)
AlzheimerGoogle&Bing	0.31 (0.15)	0.61 (0.26)	0.47 (0.24)
BigDataGoogle10&100	0.25 (0.14)	0.62 (0.24)	0.39 (0.26)
BigDataGoogle&Bing	0.23 (0.14)	0.53 (0.22)	0.41 (0.22)
Average	0.27 (0.15)	0.60 (0.25)	0.42 (0.24)

**Note:** Standard deviation values are shown in parentheses following the average

**Table V.**  
The change in top-5 and last-5 and unranked for consensus ranking-based ranking for the different experiments

	NO(unranked)	NO(last-5)	NO(top-5)
AlzheimerGoogle10&100	0.10	0.20	0.00
AlzheimerGoogle&Bing	0.10	0.60	0.40
BigDataGoogle10&100	0.10	0.20	0.00
BigDataGoogle&Bing	0.10	0.20	0.00
Average	0.10 (0.0)	0.30 (0.20)	0.10 (0.20)

consensus ranks on average did not change, and for top-5 virtually all the results remained in the top-5 subset in both rounds. The highest proportion of non-local changes and its lower decrease for consensus ranking observed for AlzheimerGoogle&Bing task may be explained by the highest proportion of relevant results which made the ranking task more difficult for the users for this query as discussed above; see Figures 1 and 2.

#### 4.3 User consensus ranking vs search engine ranking

To address the second research question of this study we compared the user consensus ranking to the search engine rankings.

As was shown in the previous section, consensus ranking-based ranking is much more stable and less subjective than individual user-based ranking. Thus, it could serve as a good reference/gold standard for evaluating search engines' rankings. To this end we compared the user consensus rankings to the search engine rankings by using the change in  $k$ -subset measure to assess the difference between these two types of ranking. The results are shown in Table VI.

For every experiment in the corresponding cell of the table the proportion of non-overlapping results is shown in the subset of top-10 and of top-5 computed for each of the two rounds separated by comma.

In general, from Table VI we can see that the difference between users' consensus and search engines' rankings in both rounds is quite considerable (20-60 per cent for the top-10 ranks) as has also been shown in a previous study (Bar-Ilan *et al.*, 2007). Figures 3-6 show the overlap and the changes in the consensus rankings between rounds, with information added regarding the rankings assigned by the search engines. The overlapping results are inter-linked with arrows, while results that were ranked in the top-10 only for one of the rounds are marked with an X icon. Moreover, the difference between users' consensus and search engines' ranking is much higher than the change between the users' consensus rankings in the two rounds of the experiment (10 per cent), as can be seen from Figures 3-6. However, the majority of results ranked in top-10 by Google were also ranked in top-10 by user consensus (again with exception for AlzheimerGoogle&Bing result set). Interestingly, comparable numbers were obtained for Google and Bing, while for one of the queries Google's ranking was closer to the consensus ranking than Bing's one (0.30 vs 0.50, respectively), and for the other query Bing's ranking was closer to the consensus ranking (0.30 vs 0.50, respectively) than Google's one.

Interestingly, for all the queries, two to three results were overlapping in the top-5 ranks for Google, Bing, and the user consensus ranking on both rounds. Also, all the results that were not ranked in the top-10 in the second round appeared at low ranks (rank 8 or lower) in the first round, which reflects higher stability in the

	Google – NO (top-10) round 1, round 2	Google – NO (top-5) round 1, round 2	Bing – NO(top-10) round 1, round 2	Bing – NO(top-5) round 1, round 2
AlzheimerGoogle10&100	0.20, 0.30	0.60, 0.60	n/a	n/a
AlzheimerGoogle&Bing	0.50, 0.50	0.60, 0.60	0.30, 0.30	0.60, 0.60
BigDataGoogle10&100	0.40, 0.30	0.40, 0.40	n/a	n/a
BigDataGoogle&Bing	0.30, 0.40	0.40, 0.40	0.50, 0.60	0.60, 0.60

**Table VI.**  
The change in top- $k$   
for  $k = 10$  (all the  
ranked results) and  
for  $k = 5$  between the  
consensus ranking  
and the search  
engine ranking

**Figure 3.**

Top-10 results of the consensus rankings for the Alzheimer Google10&100 experiment. the corresponding Google ranks are shown in the parentheses

Round 1		Round 2
1. Hebrew Wikipedia (Google 1)	→	1. Hebrew Wikipedia (Google 1)
2. Israeli Neurology Portal (Google 6)	→	2. National Institute for Neurological Disorders in English (Google 103)
3. Alzheimer's Association site in English (Google 8)	→	3. Alzheimer's Association site in English (Google 8)
4. National Institute for Neurological Disorders in English (Google 103)	→	4. Informed – Israeli Medical Portal (Google 4)
5. Informed – Israeli Medical Portal (Google 4)	→	5. Israeli Neurology Portal (Google 6)
6. Israeli Alzheimer's Association (Google 3)	→	6. Living with Alzheimer's (Google 7)
7. Living with Alzheimer's (Google 7)	→	7. Israeli Alzheimer's Association (Google 3)
8. Coping with Alzheimer's (Google 101)	✗	8. Health services in Israel: Alzheimer's (Google 107)
9. Info center for the elderly: Alzheimer's (Google 5)	→	9. Info center for the elderly: Alzheimer's (Google 5)
10. Voices of the soul: Alzheimer's (Google 105)	✗	10. Coping with Alzheimer's (Google 101)

**Note:** The change coefficient of users' consensus ranking-based ranking in two assessment rounds for this task is 0.70

Round 1		Round 2
1. Hebrew Wikipedia (G 1; B 1)	→	1. Hebrew Wikipedia (G 1; B 1)
2. Nursing homes network (G: n/a; B 10)	→	2. Informed: The Israeli Medicine Portal (G 4; B 3)
3. Portal for Living with Alzheimer (G 7; B 7)	→	3. The Hebrew Disease Index: Alzheimer's (G n/a; B 8)
4. Alzheimer's Association site in English (G 8; B n/a)	→	4. Israeli Neurology Portal (G 6; B n/a)
5. Informed: The Israeli Medicine Portal (G 4; B 3)	→	5. Alzheimer Association site in English (G 8; B n/a)
6. The Hebrew Disease Index: Alzheimer's (G n/a; B 8)	✗	6. Clalit Health Services – Alzheimer's (G n/a; B 12)
7. Take care – Alzheimer (G n/a; B 5)	→	7. Take care – Alzheimer (G n/a; B 5)
8. Alzheimer's portal (G n/a; B 2)	→	8. Portal for Living with Alzheimer (G 7; B 7)
9. RamatGan Center for Alzheimer (G 13; B n/a)	✗	9. Alzheimer's portal (G n/a; B 2)
10. Israeli Neurology Portal (G 6; B n/a)	→	10. Nursing homes network (G: n/a; B 10)

**Notes:** The corresponding Google (G) and Bing (B) ranks are shown in the parentheses. The change coefficient of users' consensus ranking-based ranking in two assessment rounds for this task is 0.80

top-7 consensus rankings than in the lower ones. For three out of four tasks in both rounds, the top result was the same as that of the search engines and for the user consensus rankings. Only for one task in the first round, was the search engine's top-ranked item ranked as second. As can be observed from Figures 3-6, there

Round 1		Round 2
1. English Wikipedia (Google 1)	→	1. English Wikipedia (Google 1)
2. YouTube video on BigData in English (Google 8)	→	2. YouTube video on BigData in English (Google 8)
3. SAS page in English (Google 4)	→	3. Hebrew Wikipedia (Google 2)
4. Hebrew Wikipedia (Google 2)	→	4. Webopedia in English (Google 9)
5. Webopedia in English (Google 9)	→	5. SAS page in English (Google 4)
6. McKinsey–BigData (Google 3)	→	6. McKinsey–BigData (Google 3)
7. NITRD group–BigData (Google 109)	→	7. NITRD group–BigData (Google 109)
8. Intel–BigData analytics (Google 107)	✗	8. World Economic Forum (Google 110)
9. Qualitest Blog (Google 104)	→	9. IBM BigData platform (Google 10)
10. World Economic Forum (Google 110)	→	10. Qualitest Blog (Google 104)

**Notes:** The corresponding Google ranks are shown in the parentheses. The change coefficient of users' consensus ranking-based ranking in two assessment rounds for this task is 0.60

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**Figure 5.** Top-10 results of the consensus ranking for the BigData Google10&100 task

Round 1		Round 2
1. O'REILLY's page in English (G n/a; B 7)	→	1. English Wikipedia (G 1; B 1)
2. English Wikipedia (G 1; B 1)	→	2. O'REILLY's page in English (G n/a; B 7)
3. YouTube video on BigData in English (G 8; B n/a)	→	3. YouTube video on BigData in English (G 8; B n/a)
4. SAS page in English (G 4; B n/a)	→	4. Hebrew Wikipedia (G 2; B 2)
5. Hebrew Wikipedia (G 2; B 2)	→	5. SAS page in English (G 4; B n/a)
6. What is BigData? (G n/a; B 9)	→	6. What is BigData? (G n/a; B 9)
7. McKinsey–BigData (G 3; B n/a)	→	7. McKinsey–BigData (G 3; B n/a)
8. Webopedia in English (G 9; B n/a)	→	8. Webopedia in English (G 9; B n/a)
9. IBM–What is BigData (G n/a; B 12)	✗	9. A day in BigData (G 11; B n/a)
10. A day in BigData (G 11; B n/a)	→	10. BigData, big decisions (G n/a; B 6)

**Notes:** The corresponding Google (G) and Bing (B) ranks are shown in the parentheses. The change coefficient of users' consensus ranking-based ranking in two assessment rounds for this task is 0.60

**Figure 6.** Top-10 results of the consensus ranking for the BigData G&B experiment

were smaller differences in the top-10 consensus ranks for the BigData query than for the Alzheimer's query, especially for the AlzheimerGoogle&Bing task, which appeared to be the most controversial and least stable according to the applied measures.

Users generally preferred English sites, when available, over Hebrew ones, and in one instance a YouTube video outranked textual results. For Bing there were cases of irrelevant results referring to a different meaning of BigData (like the music project and a recruitment management company). Quite surprisingly, for the AlzheimerGoogle10&100 task three out of top-10 results, and for BigDataGoogle10&100 four out of top-10 results in the consensus rankings were from Google's 100+ results set. These findings show that even on the tenth SERP there may be results that may be preferred to those in the top-10 shown to the users.



## 5. Conclusions and future work

Ranking of search results according to their relevance to the users is one of the primary tasks of search engines. However, this task is extremely challenging especially due to the changes over time in user preferences, which affect their assessment of search results. This paper presented an exploratory study of this issue that has not been addressed before.

The primary goal of this study was to investigate whether and how the user preferences change over time. In particular, the main idea was to test whether aggregated consensus judgements are more stable than individual user judgements and whether they are similar to the search engines' rankings. To this end, two new measures of change were proposed for ranking and relevance judgements, the change coefficient,  $\Omega(d)$ , at distance  $d$ , and the change in  $k$ -subset measure  $\text{NO}(p, k)$ , for a consecutive subset  $k$  of ranks.

To aid our investigation, a large-scale user study was conducted for ranking and judging the relevance of query result sets, and repeated the evaluation within a two-month period. It was found that the amount of changes was quite high for individual users, but the majority of changes both for relevance and ranking judgements were local within distances 1 and 2, respectively. In addition, the overlap in the top-5 and unranked subsets of the results was higher than in the last-5 subset, which implies that users are more certain about ranking of the top and least relevant results than ranking of the middle subset.

In addition, our results show that consensus ranking calculated by aggregating the individual user rankings and relevance judgements resulted in substantially fewer changes compared to the averaged individual user rankings. Finally, as in other studies (Bar-Ilan *et al.*, 2007), quite low similarity was found between the search engines' and consensus users' rankings.

Generally, understanding the user intent is beneficial, as in some cases the most relevant results may be further down the ranking list (as shown by our Google10&100 tasks). The above tendencies were quite similar for all the queries and result sets.

This is a user study with a relatively large number of participants, however, the main limitation of this study is the fact that the participants only judged the results of two informational queries they were asked to assess. In addition, this study is based on a user behaviour model, where users evaluate only a limited amount of results (20) coming from one or two search engines. The conclusions could be generalised by experimenting with more queries from a broad spectrum of topics, and also in the context of library and information science, where information seeking has been widely researched (Case, 2012).

The findings of this research contribute to understanding the user evaluation behaviour and its change over time and show a way to bridge the gap between search engines' and users' ranking and relevance evaluation. This research may have practical implications for personalisation, as users' preferences change over time and therefore the ranking of a search engine should adapt to this. For ranking, with the maximal locality threshold ( $d = 3$ ), about one third of the results undergo non-local changes, so it is these differently evaluated results that are especially in need of personalisation.

### 5.1 Implications of the study

Personalisation of search engine results has been much researched in the past decade (Keenoy and Levene, 2005; Micarelli *et al.*, 2007), although it is unclear what the uptake of personalisation has been in commercial search services, mainly due to the scale of the

problem and the unclear benefits of such an undertaking. It is well-known that the automated retrieval algorithms used by search engines take into account the popularity of user choices from analysis of the click-through data it records, however, the details of how this is done remain undisclosed. The results in this paper may provide insight to several aspects related to personalisation of search. As we have shown, there is a considerable difference between search engines' ranking and users' consensus ranking. From this we may conclude that search engines ranking of results is not fully compatible with users' preferences. Moreover, we have shown that users' judgements change considerably in time (over 30 per cent of the results have non-local changes), so this change in users' preferences is another important factor that should be taken into account when ranking search results. Personalisation on an individual level may be viable in e-commerce and internet advertising, where the benefits are clearly visible, although for search engines there is no proven model for personalisation as yet. Nonetheless, for search engines, taking the consensus ranking into account may be a reasonable solution to improving the quality of results' ranking. What we have clearly shown in the paper is that the consensus ranking is more stable than individual rankings, so apart from the computational benefits of such an approach, it is more stable than dealing with individual users where the changes are more variable and thus less predictable. There is also another positive side to the consensus ranking in that it will most likely result in a more diverse search results list (Santos *et al.*, 2015), than would arise from personalisation on an individual level.

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