

Cognitive assistance systems in manual order picking – a literature review

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Abstract. In the course of digitization, there are increasing opportunities to support the order picker with cognitive assistance systems in locating and picking stock keeping units. For this purpose, for example, pick-by-light systems, mobile devices or data glasses are eligible and are replacing paper based solutions more and more. In order to map the current state of the art in the field of human factors regarding cognitive assistance systems in person-to-goods order picking, a systematic literature review has been prepared. In total 74 publications were found in seven databases and categorized according to their focus of research and their measurement methods used. An overview of the results of numerous empirical studies on economic KPIs, such as picking-time and picking-errors, as well as the mental strain of the different technologies is given. In addition, future research fields with reference to human factors are worked out.

Keywords: order picking, cognitive assistance, literature review

1. Introduction and Motivation

Companies are facing new and complex challenges due to the increasing networking of world markets. Customers expect their suppliers to deliver products in the required quality and quantity at a competitive price and a high degree of flexibility (Handfield et al, 2013). Intralogistics are the connecting elements of the value chain in companies, where faulty or delayed deliveries can contribute to the loss of customer trust or to additional costs. Smaller order quantities, a greater number of customized products and the processing of orders in the shortest possible time results in particular challenges (de Koster et al., 2007; Tompkins, 2010). For these reasons, a functioning order picking system is needed to ensure efficient and error-free order processing.

Despite the challenges mentioned above and the constantly increasing automation, about 80% of the order picking warehouses are operated manually due to the high investment costs (Michel, 2017). In addition, manual systems are more flexible and dynamic in order to react to changes in the market situation.

An alternative to fully automatic order picking systems is the use of assistance systems such as pick-by-light, pick-by-voice or data glasses, which guide the picker and cognitively support him in his work. Especially in the context of advancing digitalization, new possibilities arise to use innovative technologies for this purpose (Rammelmeier, 2017).

On the basis of a systematic literature research, an overview of human factor based investigations of information assistance systems in manual person-to-goods order picking is presented below. The findings from publications with different assistance

systems are presented and research gaps are pointed out.

In particular, it is to be shown which performance improvements are enabled by these assistance systems and which influence they have on the quality of the work performed. Furthermore, research contributions will be presented which compare the changes in the physical and mental stress and strain of order pickers when using different cognitive assistance systems.

2. Methodology

The focus of a systematic literature review is on reproducibility, objectivity and transparency. In contrast to other forms of literature research, the aim of a systematic literature review is to identify relevant literature in neutral and well-documented way and to analyze it using qualitative methods.

The systematic literature review carried out in this article is oriented towards the defined framework of Hochrein and Glock (2012). This procedure is divided into four steps. In step one, a definition of the research focus is given and a structure of the review is presented. After preparation, the second step is to carry out the literature research and to select the literature. The selected literature will then be evaluated and categorized descriptively. The last step of the procedure includes the critical analysis, synthesis and interpretation of the literature.

The review is based on research questions on the current state of scientific research:

- Which cognitive assistance systems have been considered in research so far?
- Which parameters in ergonomics or human factors have been examined in this context?
- Which methods have been used to measure these factors?
- What are the advantages and disadvantages of the identified assistance systems when comparing with each other?

The aim of this literature review is to examine all publications published in the field of cognitive assistance systems in order picking regarding human factors and to achieve a complete coverage of this scientific field. Therefore, there are no restrictions with regard to the publication period (until march 2019) or the type of scientific literature.

A total of seven different databases were searched. As the information technology in order picking concerns different scientific fields, two large and interdisciplinary databases with a suitable topic profile, Scopus and Web of Science, were selected first. Although such bibliographies are broadly based due to their size and their interdisciplinary profile, they are surpassed in the depth of coverage by specialized databases. As a result, the specialist databases Business Source Premier, PsycINFO, PubMed, TEMA and WISO were also integrated into the research. In general, both English and German literature was included in all databases.

The keywords selected for the search were divided into two groups, of which at least one keyword existed in the title, abstract or keywords of each group. The first group uses the keyword "order picking" (as well as its German translations) to name the basic theme. The second keyword group further specifies the subject area with words that are frequently mentioned in connection with information technology assistance systems ("pick-by", "device", "display", "augmented" "reality", "guid*", "assistance", "paperless"). The publications identified in this way were checked for relevance by

reading the title and the abstract.

The snowball search was then carried out, both backwards and forwards (vom Brocke et al., 2009). In a backward search, the bibliographies of the selected papers are searched for further relevant publications. For the forward looking snowball research, Web of Science and Google Scholar were used to find titles cited by the selected articles.

The second step of the literature review comprises the search and the selection of the results. A total of 727 hits were achieved in the keyword search in the individual databases, see table 1. With 228 hits, the database Business Source Premier, followed by TEMA (148), Scopus (144) and WISO (123), leads the list of most hits. The Web of Science database achieved a lower result with 78 hits, followed by PsycINFO and PubMed with 4 and 2 hits respectively. It can be seen that the research problem considered received little attention in psychological and medical publications compared to business and technical publications.

For further consideration, irrelevant documents were sorted out on the basis of exclusion criteria. The excluded publications dealt in particular with topics such as goods-to-person order picking, order picking automation, general warehouse design or optimization models. After the selection of the literature 109 articles remained, 63 of which are duplicates. In the course of the snowball research, a further 28 articles were identified, leaving a total of 74 relevant articles for the literature review.

Table 1. Overview of the found articles and results of the different databases

		Scopus	Web of Science	Business Source	Psyc-INFO	Pub-MED	TEMA	WISO	Σ
	Hits	144	78	228	4	2	148	123	727
-	Excluded	100	50	219	2	0	132	115	816
exclusion criteria	Goods-to-person	1	4	3	0	0	2	2	12
	Automation	23	11	13	0	0	11	0	58
	Warehouse layout	13	6	12	0	0	10	0	41
	optimisation problem	16	8	22	0	0	3	0	49
	company information	2	1	33	0	0	56	76	168
	lacking quality	1	1	4	0	0	13	12	31
	other	44	19	132	2	0	37	25	259
=	number after selection	44	28	9	2	2	16	8	109
-	number of duplicates	63							
+	snowball search	28							
=	Σ	74							

3. Analysis of the identified literature

3.1 Analyzed cognitive assistance systems in the literature

In the third step of the literature review, these 74 publications are evaluated descriptively and then categorized. First, the number of publications over time was analyzed. The number of publications is increasing over time, indicating a growing interest in information technology assistance systems.

With approximately 55 %, more than half of the publications examine the pick-by-vision approach. Altogether, one quarter of the publications examined a projector as a visualization medium in addition to the data glasses. For better visibility of the large number of publications on pick-by-vision, the approach based on a projector is

therefore listed as a separate assistance system category in the following and is referred to as pick-by-projection.

Other assistance systems are dealt with much less frequently and are the following: pick-by-light (6 %), pick-by-display (6 %) and pick-by-voice (4 %). The rest of the identified papers (29 %) are comparative studies in which different assistance systems are compared with each other in experiments.

3.2 Used methods for assessment of human strain

There are mainly three parameters measured in the identified articles that fall under the category of human factors: task completion time (pick-frequency), number of pick-errors and the strain of the order picker (e.g. Baechler et al. 2016a, Battini et al. 2015).

Figure 1 shows the different survey methods for determining the order picker's strain. In total, 34 articles analyzed the strain of the order picker. Most often, individual questionnaires were used to specifically determine certain aspects of the perceived strain or discomfort of a certain assistance system. Many authors combined these examinations with a NASA-TLX (Hart & Starveland 1988), or less frequently with other standardized questionnaires like the EZ-Scale (e.g. Tumler et al. 2008) or the BFS-Scale (e.g. Grubert et al. 2010). Also, in three cases, objective methods were used by analyzing the heart rate variability of subjects in laboratory experiments (e.g. Schwerdtfeger et al. 2009).

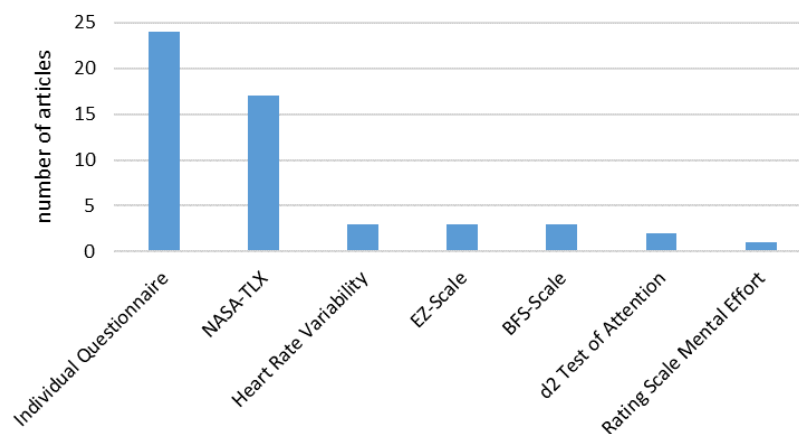


Figure 1. Measurement methods for the strain of the order picker

3.3 Comparative studies of the various assistance systems

The summary of the results of comparative studies are listed in Table 2. All studies were executed in laboratories except those of Dujmesic et al. (2018) and Baumann et al. (2012), which took place in large warehouses.

Basically, there are contradictory results in the direct comparisons between the assistance systems by the different authors. However, the pick-by-vision system tends to perform best on average in terms of the measured dimensions. Only the work of Funk et al. (2015) shows an opposite result, which may be due to the fact that the system used here had a low level of maturity. Still, e.g. pick-by-light or pick-by-voice, outperforms pick-by-vision in some other studies in terms of picking-time or picking-errors, respectively (Baumann et al. 2012, Kreutzfeldt et al. 2019). The fewest pick-errors occurred while using the pick-by-projection assistance system. Moreover, it can

also be seen that pick-by-paper is inferior to paperless picking systems in most studies.

Table 2. *Rankings of assistance systems when compared with each other regarding the pick-time (rank 1 = shortest completion time), the number of pick-errors (rank 1 = fewest errors) and the resulting strain (rank 1 = lowest strain according to NASA-TLX) of the subject*

article	rank within the comparison of pick-by-... (time/pick-errors/strain)						number of subjects
	paper	display	voice	light	vision	projection	
Reif et al. 2007	1/1/-		3/3/-		2/2/-		17
Günthner et al. 2009	2/2/-		3/3/-		1/1/-		18
Weaver et al. 2010	2/3/3		3/2/1		1/1/1		8
Baumann et al. 2012	4/4/-	3/1/-		1/1/-	2/3/-		8
Guo et al. 2014	4/3/4	2/2/2		3/4/3	1/1/1		8
Wu et al. 2015				2/1/2	1/2/1		8
Funk et al. 2015	3/1/2		2/2/3		4/3/4	1/1/1	16
Wu et al. 2016	2/3/3			3/1/1	1/2/1		12
Baechler et al. 2016a	3/3/4	2/4/3		1/2/1		4/1/2	24
Baechler et al. 2016b	4/4/3	3/3/4		1/2/1		2/1/2	21
Vries et al. 2016		2/2/-	1/1/-				101
Baechler 2017				2/2/2		1/1/1	23
Dujmesic et al. 2018		2/2/-	1/1/-				36
Kreutzfeldt et al. 2019			1/1/1		2/1/2		18

4. Discussion and Outlook

In total, six different cognitive assistance Systems have been studied in the literature so far: pick-by-paper, -display, -voice, -light, - vision and –projection, whereas the latter two have been paid the most attention. Besides analyzing the order picking-time and the number of pick-errors, many authors also measure the resulting strain of the order pickers. Most often, subjective methods, like an individual questionnaires or the NASA-TLX is used without an objective measurement as EMG or the heart rate.

Looking at the comparative studies, the question arises as to why the various comparative studies lead to such contradicting results. Most of them focus on new technologies such as pick-by-vision or pick-by-projection and only use the more established technologies such as pick-by-paper, -light and -voice as a reference. As a result, many of these established technologies in the studies are self-manufactured or wizard-of-oz approaches, due to cost reasons. So, significantly more effort is put into the newly developed systems, which makes an objective comparison difficult. For example, the pick-by-light system used by Guo et al. (2014) had weak indicator lights, which is probably why it performed significantly worse as if an industry-standard system had been installed.

Furthermore, most of the studies were carried out with relatively young subjects who had little or no experience in order picking. However, new technologies could cause problems especially for older users, who may be less tech-savvy (Baechler et al. 2017).

Therefore, no generally applicable recommendation for a specific assistance system regarding one of the three measures (time, errors, strain) can be derived - rather, this is strongly dependent on the warehouse situation, the specific application and the maturity of the corresponding technology. There is still a need for research, particularly with regard to field studies which analyze systems that meet industry standards.

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