Cognitive predictors of accuracy in quality control checking

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Abstract

Labelling errors on fresh produce are estimated to cost the UK supermarket industry £50m per year in product recalls and wastage. Such errors occur despite robust quality control procedures. Given the financial and environmental impact of these errors, it is important to understand whether label-checking performance can be predicted by individual differences in cognitive abilities. To this end, participants carried out a simulated label-checking task together with a number of measures of information processing speed, attention, short-term/working memory, and mind-wandering. Accuracy of label checking was found to be significantly predicted by three of the measures, with better short-term verbal memory being most strongly associated with performance. Cognitive tests such as these provide a means of identifying how well employees are likely to perform when undertaking such tasks and, if necessary, how they should be supported in that role, possibly forming a screening battery when recruiting new quality control staff. The findings highlight the importance of determining the component processes of cognition which contribute to performance in real-world work environments.

Keywords: Attention; Mind-wandering; Quality control checking; Short-term memory; Working memory

Introduction

A long-standing concern of applied psychology has been to provide the practical means by which to predict how well individuals are likely to perform in real-world situations along with a theoretical understanding of why this should be the case. Indeed, the motivation for developing the first tests of intelligence was not just to measure individual differences but to assist in the appropriate placement of individuals on the basis of their ability and likely achievement (Anastasi & Urbina, 1997).

With advances in the study of cognitive psychology, it has become clear that behavior relies on a variety of specific and qualitatively different resources, each dedicated to a different kind or aspect of processing (Baddeley, 2003). One resource that is essential for many everyday (and, by extension, work-related) tasks is working memory (e.g., Logie, 1993). It consists of a visuospatial sketchpad which underpins the temporary storage and manipulation of visual and spatial information, a phonological loop which is similarly engaged with auditory information, and an episodic buffer which binds together information from different sources into coherent episodes (e.g., Baddeley, 2003). Monitoring and controlling these in relation to the task at hand is the central executive, which also plays a major role in the deployment of attention, such that relevant stimuli are attended to and irrelevant ones disregarded (Engle, 2002).

The measurement of relevant specific cognitive abilities, such as the speed of information processing, the ability to direct and sustain attention, the capacity to hold and update information in memory, and the executive functions necessary to plan and execute behavior (Hambrick et al., 2010), should, in principle, provide better predictors of job performance than tests of general mental ability and hence better tools for selecting and screening employees. Yet research to date has provided little evidence that this is the case (Bosco, Allen, & Singh, 2015).

The primary challenge for research in this area is to provide a reliable basis for matching the particular cognitive skills of individuals with the demands of tasks they are, or will be, called on to perform. Clearly there are broad benefits in terms of recruitment, retention, morale and quality of performance in ensuring that employees are given work that suits their particular competencies. Failing to do so will almost certainly lead to poorer performance, and depending on the role in question, may have high financial implications or costs in terms of ill-health, injury or even death.

Advances in understanding the role of specific cognitive abilities in task performance also promise to reduce ethnic and cultural biases that occur when general mental ability is used as the sole basis for employee selection, assignment.

Such biases are likely to reduce the chances of individuals with disabilities gaining employment, even though they might be shown to be perfectly able to undertake the job if relevant specific cognitive abilities had been assessed. This may be the case, for example, for some individuals with autism who have a normal or even superior ability to attend to detail, even though they may be deficient in other aspects of cognition (Koshino et al., 2005).

There are, therefore, compelling theoretical and practical reasons to pursue research that promises to provide both a better understanding of the cognitive abilities that particular kinds of tasks require and to map these onto specific abilities individuals possess. Such matching would optimize the performance of both the individual and the system in which he or she works.

The research reported in this paper investigated whether scores on different tests of specific cognitive processes could predict the accuracy of performance on a repetitive label checking task. This task was designed to closely resemble work that is undertaken by quality control inspectors at a fresh produce packaging facility in the UK. Measures of visual search, perceptual speed, short-term memory, and attention were administered, together with a self-report measure probing the propensity of individuals to mind-wandering during ongoing behaviour.

The label-checking procedure involves an operative determining whether or not the information that appears on a given product label correctly matches details as set out on the product specification sheet (which includes information about the supermarket's order as well as the product from the producer). The number of fields of information printed on a label varies between three and eleven. Example fields are the name of the product, its weight, its country of origin and its barcode. If the information which appears on the product label does not match the specification sheet, the quality control checker should detect this and reject the label. Generally three or four independent quality control checks are performed before the order is shipped from the packaging facility to supermarket distribution depots.

Despite these stringent quality control procedures, products that are erroneously labelled do sometimes escape the packaging facility, necessitating the recall and disposal or repackaging of produce. The recall and disposal of food due to label errors is estimated to be £50 million industry-wide annually in the UK alone (S. Hinks, Product Technical Manager: Fruit and Floral, Sainsbury's Supermarkets Ltd, personal communication). Whilst infrequent, the financial and environmental costs attached to label errors are such as to drive research into their reduction.

Given the accuracy-driven and time-constrained work environment in which label-checking occurs, two different measures of the speed and accuracy with which information could be processed were administered. Visual search tasks (e.g., Wolfe, 2001) require individuals to search arrays of letters, digits, or objects to identify a particular target stimulus (e.g., the letter "T" amongst an array of other letters). Perceptual speed requires the speeded perceptual comparison of two sets of stimuli to determine whether or not they match (e.g., Salthouse & Babcock, 1991).

Short-term memory relates to the ability to store information temporarily in memory over a duration of seconds (e.g., Cowan, 2008). The task of checking information from one source with that on another seemed highly likely to draw on this memory system. The relative contributions of phonological (or verbal), spatial (relating to sequential presentations of information), and visual short-term memory to label-checking were assessed in the current study. In order to determine whether executive-loaded memory processes might also be involved in checking, further versions of the three short-term memory tasks were presented. In each of these, the simultaneous manipulation and storage of information was required, meaning that the central executive as well as the slave systems in the working memory model (e.g., Baddeley, 2003) was engaged.

The Attention Network Test (ANT; Fan et al., 2002) was employed to measure visual attention, measuring three different networks: the alerting network, the orienting network, and the executive control network. The alerting network aims to maintain an alert and vigilant state of readiness for information processing, the orienting network selects task relevant information from the visual input, and the executive control network resolves conflict among possible alternative responses. When checking a label, an operative has to be alert to the possibility of a mismatch between the label and the specification sheet. They must also be able to orient their attention to the specific information being checked, whilst ignoring the potentially distracting, but related visual information in the surrounding area. Finally, under this account, the executive control network would be called upon to decide if a mismatch response is valid or not.

Mind-wandering occurs when an individual has thoughts unrelated to the task which move attention from the intended task. The Daydreaming Frequency Subscale (DFS; Singer & Antrobus, 1970) was used to measure individual differences in the propensity to mind-wandering. In contrast to the ANT, which gives an indication of how well an individual copes with potentially distracting information from the external environment, the DFS gives an indication of how an individual copes with distractions which are internally generated. Of particular relevance to the current study is evidence that the incidence of mind-wandering is relatively high whilst completing undemanding tasks but decreases as the task demands increase (McKiernan et al., 2006). Since label-checking is repetitive and merely requires operatives to select, read, and check information on labels against a specification sheet, it was considered likely that mind-wandering would occur.

Together, the battery of tests was designed to measure a broad range of specific cognitive functions that might underpin and predict performance on label checking and other quality control tasks that require the identification of mismatches or mistakes.

Method

Participants

A total of 51 university students (44 females, 7 males, mean age = 24 years, *SD* = 6) took part in the experiment. They received a small honorarium or course credit in appreciation of their participation. All of the participants reported themselves to be naïve to the quality control processes involved in checking fresh produce labels.

The participants were either native English speakers or were studying at undergraduate degree level with an International English Language Testing System (IELTS) score of at least 6.0 (the minimum requirement of London South Bank University for entry to its degree courses).

Materials

The label-checking and visual search tasks were programmed and run in Experimenter Builder Version 1.4.128 B (SR Research Ltd., Ontario, Canada). E-Prime 2.0 (Psychology Software Tools, Inc., Sharpsburg, PA) was used to program and implement the remaining computerized tasks.

Facsimiles of the product specification sheet and labels used in the packaging facility were created for the purpose of the experiment (Figures 1 and 2 respectively). The number of fields of information per product on the specification sheets and produce labels was held constant at seven. These fields of information were the product (the type of fruit or vegetable, e.g., baby courgettes), country of origin, the grower (the name of the company which grew and shipped the product), the quantity of items contained in the packet (i.e., the weight of the product), its best-before date (indicated by "BB" on the specification sheet), the product's barcode number, and details of any promotion ribbon or label to be appended to the packaging (i.e., any promotional activity on the product being offered by the supermarket, such as "Any 2 for £2.50"). In the course of the block of trials, fifty different labels were presented.

The produce label and the product specification sheet were presented simultaneously on a 21"colour monitor screen, with the former occupying the top half and the latter the lower half of the display.

A head-rest was used in the label-checking task in order to minimize the head movements of the participants.

PRODUCT	COUNTRY	GROWER	QUANTITY	BB	BARCODE	Promotion Ribbon / Label
COURGETTES	PORTUGAL	EMERGOSOL	500g	05-Dec	0108 5808	MIX & MATCH Any 2 for £2.50
SWEET FRAGRANT GOLDEN NECTARINES	BUFLAND, SOUTH AFRICA	UNICO - YELLOW FLESH	X 4 FRUIT	30-Nov	0012 1705	MIX & MATCH Any 2 for £4
STRINGLESS BEANS	MOROCCO	LARA CASTANEDA	225g	01-Dec	0012 1705	
PEACHES	CAPE-TWA, SOUTH AFRICA	SUPECH 15 - YELLOW FLECH	X 4 FRUIT	30-Nov	0048 5203	
SWEET FRAGRANT GOLDEN NECTARINES	BUFLAND, SOUTH AFRICA	MAYGLO - YELLOW FLESH	X 4 FRUIT	30-Nov	0012 1705	£2.25

Figure 1: An example of a product specification sheet.

Figure 2. An example of a product label.

Design

Label checking task

A block of 50 trials was presented. The information displayed on the product specification sheet and that presented on the label matched on 40 of these trials. For the remaining 10, there was a mismatch between the two sources of information. For each trial where there was a mismatch, only one field of information varied between the product specification sheet and the produce label (e.g., the best-before date). The field of information that differed was varied pseudo-randomly over the 10 trials such that the errors appeared in different fields. Responses to these trials were logged as correct when a mismatch between the information set out on the product specification sheet and the label was indicated by the participant.

The participants undertook two further 50-trial label-checking blocks after this initial block. The data relating to these are reported in Smith-Spark, Katz, Marchant, and Wilcockson (2015). The focus of the current paper, however, was purely on the extent to which the initial label-checking performance of individuals with no prior experience or training could be predicted on the basis of scores from the battery of cognitive tasks which was administered to them.

Cognitive tests

Visual search ability was measured using a modified version of Triesman and Souther's (1985) letter finding task. Participants were presented with an array of 19 letter stimuli (namely, N, C, F, K, and P). In one block of trials, they were asked to locate a normal, forward-facing letter in an array of backwards, mirrored letters. In a separate block of trials, the participants were asked to identify a backwards letter amongst an array of normal, forward-facing letters. In each case 1, 2, or 3 letters faced in the opposite direction to the others. Participants were asked to indicate how many backwards-facing letters they had seen. Performance on the backwards and forwards trials was combined to give mean RT and accuracy scores for visual search ability.

Perceptual speed was measured using a letter comparison task, modified from Salthouse and Babcock (1991). Two pages with multiple pairs of 3, 6, or 9 letters were presented which participants had to decide were the same or different. The task for the participant was to write the letter “S” between the pair if the two members were the same and letter “D” if they were different. Mean perceptual speed and accuracy scores were derived from the two measures as the total number of correct responses made in 60s. A number comparison task followed this using the same design but with multiple pairs of numbers.

Phonological short-term memory was assessed by the Digit Span Task. Participants were presented with a sequence of single digit numbers, one at a time. Once the sequence was completed, they were asked to recall the digits in the order they had been presented. The number of digits gradually increased over trials, starting with two and going up to a maximum of 10. Three trials were presented at each level. At least two of the three trials needed to be correct in order to advance to the next level of the task. A participant’s span length was taken as the last level at which they could reliably remember the sequence of digits in the correct serial order. A backward digit span task was also administered in which participants had to report the digits in reverse serial order, thereby drawing on working memory rather than simply short-term memory to store and manipulate information simultaneously.

The Corsi Block span test (Corsi, 1973) was used to measure spatial working memory. An array of 12 squares was presented. Squares in the array were highlighted in sequence one at a time. At the end of the sequence, the participant was asked to indicate the locations of the highlighted squares in the correct serial order. The number of squares highlighted increased over trials from two up to a maximum of 10. Three trials were presented at each level of the task, with span being taken as the last level at which the participant was entirely successful in recalling at least two out of the three trials correctly. The total number of cells whose location was correctly recalled in serial order was recorded. A further version of the task was presented, the Corsi backward task, which required the reporting of the spatial sequence in reverse serial order, again tapping working memory resources.

A modified version of the Visual Patterns Test (Della Sala et al., 1999) was used to measure visual working memory. Participants were presented with different arrays of black and white squares, after each of which they had to recall the pattern by indicating which squares were white and which were black. The number of squares in the array increased during the course of the experiment. A second version of the task which placed demands on working memory was administered. It required participants to invert the colours of the squares when reporting them. In both versions, the total number of cells that were correctly identified was logged.

The ANT (Fan et al., 2002) was used to measure visual attention. Participants were shown a cue (‘*’) and required to indicate the direction in which a central target arrow pointed. This target arrow appeared either above or below the fixation point in the middle of the screen. It was surrounded by a set of distractors that consisted of either congruent arrows (pointing in the same direction), incongruent arrows (pointing in the opposite direction) or lines that were considered neutral. The cues (‘*’) could assist performance (in that the spatial cue was presented in the same location as the following target arrow - above or below fixation), distract from performance (when the spatial cue was presented in an opposite location to the following target arrow), act neutrally with respect to performance (central cue at fixation and double spatial cues above and below fixation), or there may be no cue present. Performance on the alerting network was calculated by subtracting the mean RT of the double-cue conditions from the mean RT of the no-cue conditions. To assess performance on the orienting network mean RT of the spatial cue conditions were subtracted from the mean RT of the center cue condition. Finally, for the executive control (conflict) network the mean RT of all congruent flanking conditions, summed across cue types, were subtracted from the mean RT of incongruent flanking conditions.

The Daydreaming Frequency subscale (DFS) of the Imaginal Process Inventory (Singer & Antrobus, 1970) was used to measure self-reported propensity to mind wandering. Participants rated twenty-four statements on a 1-5 scale, with higher scores indicating a greater frequency of mind-wandering. An example statement is “When I am not paying close attention to some job, book or TV, I tend to be daydreaming ...”, with participants choosing one of the following options: 1 = 0% of the time, 2 = 10% of the time, 3 = 25% of the time, 4 = 50% of the time, and 5 = 75% of the time.

Statistical analysis

A multiple stepwise regression was run with the cognitive test measures entered as predictor variables. Overall label-checking accuracy was the outcome variable.

Procedure

Informed consent was given by all participants to take part in the experiment. Before the checking task began, the participants were seated at a viewing distance of 55cm from a 21” computer monitor. They then viewed a 10-minute slide show presentation. This provided them with a detailed description of the label layout, specification sheet layout, general task instructions, the nature of errors, etcetera.

During the label-checking task, the participants indicated whether or not the information presented on a given label was correct, checking it against the appropriate entry on the specification sheet. They were instructed to respond as quickly but as accurately as possible. Responses were made by pressing designated Yes and No keys on a standard QWERTY keyboard.

The cognitive measures were administered in a separate testing session. The order in which the cognitive tasks were presented was counterbalanced between participants. The letter and number comparison tasks had a pen-and-paper format, while all others were computerized.

The participants were debriefed upon completing testing.

Results

The scores from three participants were removed on the backward search and two on the forwards search due to their having mean scores more than 2.5 SDs from the overall mean.

The overall mean proportion accuracy of label-checking was .85 (SD = 0.05).

Descriptive statistics for each cognitive test are displayed in Table 1, together with Pearson's correlations indicating the extent of the relationship between each test and label checking accuracy.

Table 1: Descriptive statistics

Cognitive process	Cognitive test	Mean (S.D.)	Correlation with label checking accuracy (*r*)
Visual search	Letter finding		
	1.Speed	6945.50 (1723.45)	-.002
	2. Accuracy	25.51 (3.10)	.017
Perceptual speed	Comparison task		
	1. Speed	25.65 (6.16)	-.110
	2. Accuracy	23.01 (4.87)	-.014
Phono-logical short-term memory	Digit Span		
	1. Forward	7.34 (1.48)	.358*
	2. Backward	5.90 (1.61)	.042
Visual memory	Visual Pattern Test		
1. Short-term	1. Original	82.46 (19.91)	.117
2. Working	2. Inverted	58.51 (35.05)	.041
Spatial memory	Corsi Block Span Test		
1. Short-term	1. Forward	43.37 (13.01)	-.304*
2. Working	2. Backward	13.63 (6.89)	.087
Attention	Attentional Network Test		
	1. Alerting	23.92 (26.17)	.093
	2. Orienting	53.95 (30.25)	.061
	3.Executive control	114.64 (45.35)	.127
Mind wandering	Imaginal Process Inventory	67.76 (15.94)	-.120

Key: * = $p < .05$

The stepwise multiple regression analysis indicated that overall label-checking accuracy could be significantly predicted by the cognitive predictors, $R = .637$, adjusted- $R^2 = .358$, $F(3, 37) = 8.44$, $p < .001$. Three predictors were entered in the final three-step model. These were digit span forwards, standardized-β = .658, $p < .001$, Corsi forwards, standardized-β = -.395, $p = .004$, and perceptual speed, standardized-β = -.459, $p = .004$.

Discussion

The simulated label checking task used in this study resulted in a rate of errors somewhat greater than that indicated by the historical record at the actual packing facility on which it was modelled (approximately 15% as opposed to 2% of checks). While the stimuli were virtually identical, the laboratory-based task did entail many more checks and in a more concentrated time-frame than demanded in this and most likely other real-world situations.

The results indicate that label-checking accuracy can be significantly predicted on the basis of the cognitive tasks employed in this experiment. Verbal short-term memory (as measured by the digit span forwards task) was the strongest predictor of performance, with the ability to retain a larger number of digits in memory being associated with higher accuracy. The next strongest predictor was perceptual speed although, in this case, the relationship was negative. It would appear that processing information more rapidly was associated with lower accuracy, which may indicate a speed-accuracy trade-off. Spatial short-term memory (measured by the Corsi forwards task) was also a significant negative predictor of accuracy. Although it may seem paradoxical that the ability to hold more spatial information in memory would be associated with poorer accuracy, it may be that a stronger spatial memory encouraged individuals to adopt a non-optimal approach to label-checking, in particular chunking (e.g., Miller, 1956). A chunking strategy in which several bits of information from the specification sheet are checked in one visual pass of the produce label, has previously been found to be associated with lower levels of checking accuracy than a more systematic approach in which one piece of information at a time is taken from the product specification sheet and checked against the label (Smith-Spark, Katz, Marchant, & Wilcockson, 2015).

Whilst null results should be treated with caution, the results suggest that cognitive tasks involving greater executive resources do not predict performance, since none of the executive-loaded span tasks were significantly associated with label-checking accuracy. Further to this, neither visual search abilities nor the ANT predicted performance, suggesting that neither visual search nor the attentional processes tested by the ANT contribute to label-checking accuracy. Finally, mind-wandering, as measured by the DFS), did not predict correct responses on the label-checking task.

The present study explored the value of tests of specific cognitive functions as predictors of performance on a simulated label checking task. Unlike most research in applied areas of occupational psychology, this experiment had well defined, objective outcome measures and allowed a reasonably close mapping between the behavioural requirements of the task, i.e., perceptual scanning, comparison, no problem solving, etc., with narrowly defined cognitive processes which one would assume underpinned these actions, such as visual search, focused attention, executive control and short-term memory. While some success in prediction was gained, the experiment also demonstrated the challenge in determining the connection between specific cognitive abilities and task performance. This is partly because there are different ways in which a given task, even a relatively straight-forward task like label checking, can be approached (Smith-Spark et al., 2015). Differences in the choice of strategy may account for a substantial proportion of the variability associated with task performance and relate, in turn, to prior experience and even general mental ability of individuals (Hambrick et al., 2010).

Aside from the strength and availability of specific cognitive resources, some of which have been measured in the current experiment, performance also depends on the demands of situational factors such as time constraint, interruptions, incentives and cognitive load, and as importantly non-cognitive factors such as previous experience, motivation and conscientiousness. Together these lead to cognitive dynamics which are variable and difficult to predict, as seen in the negative contribution of spatial memory and processing speed to the accuracy of performance. Given the manifold nature of cognition, even basic procedural tasks such as label checking, may resist an exhaustive description of the contribution of specific cognitive processes to performance. This is probably why tests of general cognitive ability have generally proven to be superior predictors of job performance as well as the preferred basis for employee selection and allocation (Schmidt, 2002).

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