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Comparison of in-sight and handheld navigation devices toward supporting industry 4.0 supply chains: First and last mile deliveries at the human level

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ABSTRACT

Last (and First) mile deliveries are an increasingly important and costly component of supply chains especially those that require transport within city centres. With reduction in anticipated manufacturing and delivery timescales, logistics personnel are expected to identify the correct location (accurately) and supply the goods in appropriate condition (safe delivery). Moving towards more environmentally sustainable supply chains, the last/first mile of deliveries may be completed by a cyclist courier which could result in significant reductions in congestion and emissions in cities. In addition, the last metres of an increasing number of deliveries are completed on foot i.e. as a pedestrian. Although research into new technologies to support enhanced navigation capabilities is ongoing, the focus to date has been on technical implementations with limited studies addressing how information is perceived and actioned by a human courier. In the research reported in this paper a comparison study has been conducted with 24 participants evaluating two examples of state-of-the-art navigation aids to support accurate (*right time and place*) and safe (*right condition*) navigation. Participants completed 4 navigation tasks, 2 whilst cycling and 2 whilst walking. The navigation devices under investigation were a *handheld* display presenting a map and instructions and an *in-sight* monocular display presenting text and arrow instructions. Navigation was conducted in a real-world environment in which eye movements and device interaction were recorded using Tobii-Pro 2 eye tracking glasses. The results indicate that the *handheld* device provided better support for accurate navigation (right time and place), with longer but less frequent gaze interactions and higher perceived usability. The *in-sight* display supported improved situation awareness with a greater number of hazards acknowledged. The benefits and drawbacks of each device and use of visual navigation support tools are discussed.

1. Introduction

An increase in global population coupled with a reduction of resources necessitates a move toward sustainable practices within society and manufacturing industries (Siemieniuch et al., 2015). These challenges are targeted in manufacturing within the Fourth Industrial Revolution also referred to as Industry 4.0 (Kagermann et al., 2013). Within the Industry 4.0 paradigm, data are collected and utilised from the Internet of Things (IoT), people and services. Data from digital devices (e.g. the geographical location from the Global Positioning System (GPS) (U.S. Government, 2019)), contributes toward the Industry 4.0 vision of near real-time data for greater supply chain visibility, security and traceability (Barreto et al., 2017; Hofmann and Rüsch, 2017). Logistics companies are responding to increasing demands for reduced duration and cost (environmental and economic) of commercial journeys through the adoption of smaller "cleaner" urban distribution units located within cities combined with more sustainable delivery options (Ridgway et al., 2013; Schliwa et al., 2015). The use of crowd sourced couriers (e.g. cyclist and pedestrian) could provide a lower cost service, reduced congestion and lower emissions and be particularly suited to the last mile and metres of delivery in cities and urban areas (Mladenow et al., 2016; Wang et al., 2016).

Successful delivery is a critical component of logistics, requiring the right *product* delivered to the right *place*, right *time* and in the right *condition* (Barreto et al., 2017). To achieve the right *time* and right *place* requirements a digital navigation device may be used to locate

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unfamiliar destinations (May 2013). To achieve deliveries in the right *condition*, a courier must navigate safely through maintaining situation awareness (SA) through perception and comprehension of the elements in their environment (Endsley, 1995) and adjusting behaviour in response to potential hazards. The use of a navigation device may negatively affect SA increasing the risk of injury to courier or goods (wrong *condition*). If the navigation device increases cognitive load this may also result in compensatory physical behaviour by the user, such as slowing down or stopping (Kircher et al., 2015; Chung et al., 2016) resulting in late deliveries. An ideal navigation device should therefore help a courier achieve successful delivery to the right place, within the agreed time scale whilst enabling them to maintain SA to avoid potential hazards (i.e. delivery and courier undamaged by incident or environment).

The reviewed literature does not specifically address requirements of an Industry 4.0 courier in a real-world setting considering both navigation accuracy and safety. To address this gap the present study has been conducted to compare two visual digital navigation aids in a real-world. The paper is formed of 6 sections. Section 1 presents an introduction to courier safety (1.1), the variety of available navigation aids are briefly discussed (1.2) and study aims are detailed (1.3). Section 2 presents the study Materials and Methods comprising details of a pilot study (2.1), participant information (2.2), the experimental setup (2.3), stimuli including routes and devices (2.4) and measures (2.5) used for navigation accuracy (2.5.1), safety (2.5.2) and usability (2.5.3). The results of the study are summarised (3) within the Discussion (4), Limitations (5) and Conclusions (6) sections.

1.1. Courier safety

Due to their lower mass, slower speed and unshielded status, cyclists and pedestrians are categorised as vulnerable road users (Chong et al., 2010). Whilst navigating to their delivery destination, couriers will be required to maintain SA and negotiate numerous hazards. The types of hazard negotiation will vary between countries and is dependent upon infrastructure/legislation (e.g. cycling or pedestrian only lanes, laws governing rights of way) (Mwakalonge et al., 2015) and human factors (e.g. risk perception, road sharing tolerance) (Chaurand and Delhomme, 2013). Commonly encountered hazards include static features including curbs or rough ground, or developing hazards such as motorised vehicles, cyclists and pedestrians (Vansteenkiste et al., 2014).

A courier may be operating under additional cognitive demands if they are required to follow specific routes (for security or traceability), meet delivery time slots or deliver to high traffic and hazardous areas (GMB Union, 2018). Secondary tasks, for example interacting with a navigation device, reduce the cognitive resource available to maintain SA (Yang and Wu, 2017) and reduce hazard perception. In a study of distracted drivers on U.S. public roads, the main causes of fatal traffic accidents were identified as using a technological device or engagement in inattentive activities such as conversation or tasks not related to driving (Stimpson et al., 2013). Similar distraction effects have been observed in studies with pedestrians (Schwebel et al., 2012; Mwakalonge et al., 2015) and cyclists (de Waard et al., 2010; Yang and Wu, 2017).

Cyclists and pedestrians are particularly vulnerable when they are required to share space with motorised vehicles and when crossing streams of traffic (Chong et al., 2010). Although cyclists and pedestrians generally operate at slower speeds than motorised vehicles, they share spaces and many of the potential hazards. To reduce the loss of SA while using devices whilst driving, it is recommended that frequency of glances/gazes towards devices are minimised and below 2 s in duration (NHTSA, 2012) and the same advice may aid cyclists (Yang and Wu, 2017). In a review of injuries sustained by cyclists in North Carolina between 1997 and 2002, Kim et al. found the greatest percentage of accidents occurred when the cyclist was turning or merging into motorised traffic streams (23.9%) with 55% of incidents classified as the fault of the cyclist particularly at crossings and junctions (Kim et al., 2007). Similarly, Hwang et al. reported that 20.3% of pedestrian accidents in the U.S. occurred at intersections (Hwang et al., 2016) and experienced higher exposure to injury and fatal crashes than car drivers (Chaurand and Delhomme, 2013).

1.2. Navigation devices

A navigation device consists of two main elements: the *information* presented to the user (comprising encoding and content) and the *device* itself (location, position, interaction method). *Information* encoding affects perception and subsequent interpretation of information. The navigation information can be visually, auditorily or haptically encoded, for example via maps, spoken instructions or physical vibrations. The *device* may be characterised in terms of size/location, method and required interaction and the reliability of software and hardware in outdoor conditions.

To select an appropriate device for couriers the hands busy nature of the task (safely handling delivery items) and additional devices couriers may be required to carry (e.g. mobile phone, parcel tracking/scanning or label printer) need to be considered. These additional devices may be larger and heavier than commercial devices due to the need for compliance with standards such as MIL-STD-810G (U.S. Government, 2008) making hands free options appealing.

1.2.1. Auditory navigation

Auditory navigation is hands free and does not require users to remove their gaze from the road ahead. Although the half-life of auditory information degradation (≈ 1500 ms) is longer than visual (≈ 200 ms) (Card et al., 1983), the transient nature of both sound (and haptic, see section 1.2.2 below) signals mean that the information does not persist once the signal has been transmitted. Additionally it is harder to present an overview auditorily than it is visually (Munzner, 2014). Audio navigation has been successfully utilised in simulated/laboratory environments (Lokki et al., 2000; Larsen et al., 2013) and for supporting people with low visual acuity (Lewis et al., 2015). However, difficulties encountered during real-world use include a lack of awareness (prediction) of incoming instructions and difficulty hearing instructions in noisy environments (Albrecht et al., 2016; de Waard et al., 2017). Audio instructions may be distracting to cyclists (Dancu et al., 2015) as they need to be able to hear approaching traffic or environmental alerts (de Waard et al., 2017). Bone Conduction (BC) headphones transmit sound directly to the inner ear via the wearers cranial bones allowing the outer ear to remain "open" to environmental sound, marketed as a safer way to engage with audio compared with in-ear headphones (May and Walker, 2017). Nevertheless in an evaluation of wearers perception of environmental sound and distractor sound origin, May and Walker found that BC headphones reduced accurate perception of critical environmental sounds (May and Walker, 2017).

1.2.2. Haptic navigation

Haptic or tactile/vibration instructions keep the users' hands free and allows both eyes and ears to focus on maintaining environmental awareness (Steltenpohl and Bouwer, 2013). Haptic feedback may be particularly useful in low visibility environments or military scenarios requiring stealth (Aaltonen and Laarni, 2017). Navigation support for cyclists has been explored using vibrating handlebars (Poppinga et al., 2009) or a vibrating belt, however, participants were observed to cycle slower in order to feel the vibrations (Steltenpohl and Bouwer, 2013), suggesting such methods may not suitable for time constrained deliveries. Early pedestrian examples include wearable shoulder tapping devices (Tan and Pentland, 1997; Ross and Blasch, 2000), but these solutions would require a courier to wear a cumbersome device in addition to their cargo pack and other devices. As with auditory instructions, the person is passive in receiving instructions as and when they are sent by the system.

1.2.3. Visual navigation

In the case of both auditory and haptic instructions, a person passively receives the information sent by the system. Visual encoding supports the human ability to process information *pre-attentively* enabling quicker comprehension of presented information (Munzner, 2014). The benefits of visual encoding suggest that this is potentially the best option for courier support in a wider range of environmental conditions (e.g. noisy, real-time hazards or road vibrations). Glances away from the road, e.g. fixating on navigation device, for longer than 2 s are considered particularly hazardous and should be avoided (NHTSA, 2012; Yang and Wu, 2017). Although traditional *handheld* visual displays require the user to divert their gaze from the road, they support self-paced viewing (Kircher et al., 2015). External visual maps play an important role in interpreting instructions for wayfinding (Bjerva and Sigurjónsson, 2016) and can be used to help build the user's internal mental map. An external map that matches the real world may reduce cognitive load by lessening the need for mental translation associated with symbols (Bjerva and Sigurjónsson, 2016). The use of simplified representations such as icons and text have been proposed to compensate for limited working memory and the basic shapes allow for fast perceptual processing (Albrecht et al., 2016; Chung et al., 2016).

To provide hands free navigation information and reduce diverted SA or glances away from the road, projection and head mounted displays or Heads Up Displays (HUDs) have been proposed. Wearable HUD devices present the user with information directly in their visual field. A small screen displaying information is worn attached to a pair of glasses or helmet. These aids reduce glances away from the road and improving safety by providing salient information in the users line of sight (Ross and Blasch, 2000) while supporting self-paced interaction. The closer proximity of information when using a HUD may be preferable to a road surface projection (Dancu et al., 2015) and at present projection is not optimal for day time navigation due to the interference of daylight with projected images. Low operational costs have been reported as one of the main benefits of cyclist couriers (Maes and Vanelslander, 2012), indicating that expensive overheads for support devices need to be justified. Binocular HUD/navigation systems utilising global positioning systems (GPSs) are not widely available commercially and at present are relatively expensive (ODG, 2018). Monocular displays are more widely available commercially and despite potential ergonomic issues such as eye strain (Patterson et al., 2006) they have been recommended to support hands free visual navigation of couriers (Glockner et al., 2014). Monocular displays allow for the provision of information within the users' sight line without obstructing the surrounding field of view thereby reducing the need for glances away from the road.

1.3. Study aims

The present study is aimed at improving supply chain performance through appropriate support of the delivery courier. The selection of appropriate display mechanism to support couriers has not been defined in the literature to date hence two representative devices using visual encoding in: (i) a *handheld* format (using detailed map) and (ii) an *in-sight* display (using simplified icons and text) were selected for further evaluation, a summary of the study aim is presented in Fig. 1.

As indicated in the literature, successful deliveries require a courier to deliver items to the right *place* at the right *time* and in the right *condition*. In addition to these requirements the device should be perceived as useable as an indicator of potential adoption by end users (Rubin, 1994). Towards identifying suitable navigation devices for Industry 4.0 couriers, the following research questions have been posed:

- RQ1: Does the device support right time and place delivery (Accurate navigation)?
- RQ2: Does the device support right condition delivery (Safe navigation)?
- RQ3: Is the device perceived as useable (Useable navigation)?

2. Material and methods

2.1. Pilot study

A pilot study (n = 4, all male) was conducted in which three major issues were identified and rectified prior to the main field experiment. Firstly, the destination should be unfamiliar. If the participants were familiar with or were able to identify the destination (specifically on the *handheld* device map) they did not refer to instructions. Secondly, all four navigation routes must be completed within 1 h to avoid fatigue. Thirdly, the researcher must remain out of line of sight and behind the participant. If accompanied alongside or within line of sight, the participant would rely on the researcher for hazard detection and expect to receive navigational prompts.

2.2. Participants

Following approval of the study through the university ethics committee, 25 participants were recruited from the university undergraduate and postgraduate populations (2 female). The participants were predominantly young and male (mean age 20.8, standard deviation (SD) 1.9, max 28, min 18). All participants self-reported as healthy with normal or corrected to normal vision. Participants were not incentivised for participation and were comfortable both cycling and walking for up 30 min at a time and up to 1 h.

2.3. Experimental setup

The experimental protocol selected was a semi-controlled *field* experiment to gain both quantitative and qualitative understanding of device use in real-world conditions (Kircher et al., 2015). All sessions were completed individually between February and March 2018 in the UK, outside on dry days, during daylight hours and lasted between 40 min and 1 h. Following informed consent, participants completed demographic and device familiarity questions. Participants were introduced to the study using a script to reduce variation of experience. The eye tracking glasses were fitted and calibrated using the manufacturers single point calibration procedure (Tobii, 2016). Participants were taken to a practice walking route (i.e. 500 m including navigation on named and unnamed path, no time limit) using the *handheld* and *in-sight* display simultaneously. The participants were able to ask questions regarding operation of the devices and once comfortable they commenced the timed routes.

2.4. Experimental stimuli

2.4.1. Routes

Participants were required to complete four routes during a 1-h session. Routes were assigned to ensure each participant completed two walking and two cycling routes, using each device twice. Route combinations were counterbalanced to reduce ordering effects. A total of 12 participants completed each experimental condition, resulting in 96 routes in total. There was no overlap nor repetition between routes, however all routes started from or returned to the set-up location (i.e. representative of a typical delivery hub). Two of the routes were classified as *simple* and two as *complex* navigation tasks. *Simple* routes utilised only named roads and junctions (i.e. < 3 options). *Complex* routes included unnamed roads, navigation through a carpark and complex junctions (i.e. > 3 options). Simple and Complex routes were the same length and predicted completion times according to the mapping software (e.g. 0.3miles within 6 min walking, 0.4 miles within 4 min cycling). A facilitator accompanied the participants at a distance of ~3 m

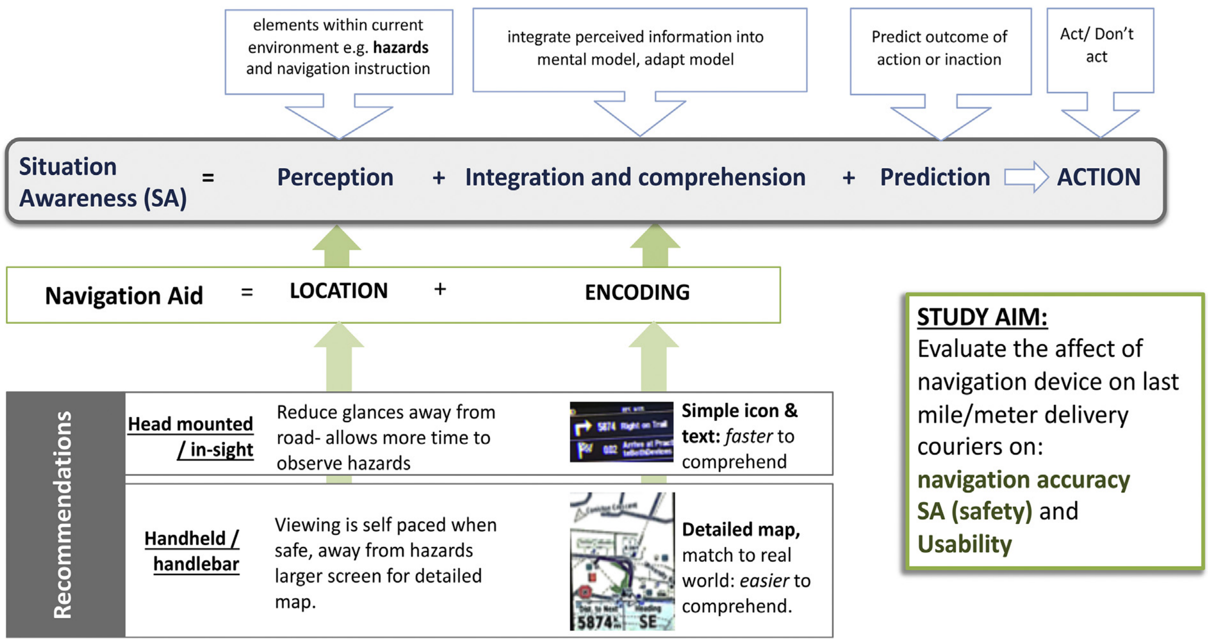

Fig. 1. Illustration of the potential influence of navigation devices location and encoding of information on the situation awareness and action of couriers.

behind (out of their line of sight) to reduce their influence on the navigation behaviour as observed during the pilot study. The facilitator was instructed to stop the session if the participant had deviated from the route for more than 5 min, to intervene as necessary to rectify device issues (e.g. failed GPS or device connection, crashing or freezing of display screen) and to ensure participant safety.

2.4.2. Navigation devices

The evaluated devices were considered to be representative of state-of-the-art navigation devices, i.e. visual navigation displays in the format of *handheld* and *in-sight* platforms. In order to reduce the potential effects of device familiarity or device differences, dedicated, commercially available devices for navigation were selected. The example of a *handheld* device selected was the *Garmin Edge 1000* (Garmin, 2017a) henceforth referred to as *handheld*. The device could be held by a pedestrian or mounted on handlebars for a cyclist. The *in-sight* display device used was the *Garmin Varia Vision* (Garmin, 2017b), henceforth referred to as *in-sight*. The *in-sight* device presented a heads-up view using text and arrows and is worn on glasses for viewing on either the right or left eye. Both modes of presentation (i.e. *handheld* and *in-sight*) used same software ensuring no differences between GPS capability or underlying software functionality. The selected devices are shown in Fig. 2.

The two devices were evaluated according to the method used by de Waard et al. (de Waard et al., 2017) to ensure they met essential display criteria for road users as reported by Green et al. (Green et al. (1994). The 5 criteria were identified as: (i) *Basics*: requiring minimal information and maintaining legibility if items are added, (ii) *Legibility*: minimum text 6.4 mm height according to the Bond Rule, (iii) *Understandability:* use of common abbreviations, (iv) *Organisation:* hierarchical and proximal information and (v) *Content*: accurate road names and user movement feedback.

Both devices complied with content and understandability requirements. The larger screen on the *handheld* device allowed for an ego-centric map with turn-based instruction whereas the smaller *in-sight* display utilised simplified text and arrows with the users' movement indicated by changing distance to next navigation step. To ensure *legibility*, the *handheld* device was viewed at a maximum of an arm's length in a position determined by the user for maximum comfort, or mounted to the bicycle handlebar both within 90 cm of the users head (de Waard et al., 2017). The *in-sight* display was attached to glasses and viewed at a maximum distance of 5 cm from the eye with a small adjustment (+/− 1 cm) for individual users to ensure legibility and comfort. Based on the reviewed literature it may be hypothesised that the *handheld* device could aid self-orienting due to the real world visual map (Aaltonen and Laarni, 2017), whereas the *in-sight* display should reduce glances away from the road and improve SA (Montello and Sas, 2006).

2.5. Measures

Eye tracking is a method commonly utilised for studying road user gaze behaviour to identify causes of distraction and potential reduction in SA resulting in dangerous behaviour based on the direction of the user's gaze *fixation* (Topolšek et al., 2016). *Fixation* is defined as the suppression of eye movements where the eyes remain still with the person directing their gaze toward an object/area of interest (i.e. within ± 0.5°) for a period of time ranging from 30 to 40 ms during reading to 200–300 ms during observation tasks (Holmqvist et al., 2011). Additional verbal protocols were utilised in the present research to verify perception of hazards and account for possible fixation without the user being cognisant of where they had directed their gaze (Holmqvist et al., 2011). Tobii Pro 2 eye tracking glasses (Tobii, 2016) were selected to record video, gaze fixation and audio data written to a mobile unit that can be carried in a backpack (weight = 312 g). Due to the real-world nature of the experiment and inherent variations in light conditions, limitations in the performance of the eye tracking equipment were expected. Video and audio recordings were used to evaluate route completion accuracy (compared with mapped route), hazard perception and device interaction. Eye movements were classified using the Tobii Pro filter I-VT attention (fixation classified as ± 0.5° for > 60 ms) (Olsen, 2012). Eye movements recorded as *unclassified* or *eyes not found*, e.g. blink, were not used. The recordings were reviewed by three independent researchers (one with 50 + hours experience in eye tracking studies, another expert in traffic management and the third independent). Data were analysed using Tobii Pro Software, Microsoft Excel, IBM SPSS and MATLAB.

2.5.1. Accurate navigation (RQ1)

Route completion time was defined as the time taken from the participant viewing the first instruction to arriving at anticipated

Fig. 2. Left: in-sight display attached to glasses (top), handheld unit (bottom). Middle: relative size of units. Right: illustration of instructions as shown on in-sight display (top) and handheld (bottom).

Table 1
Route completion classification and scoring metrics used to evaluate support of Right Time, Right Place delivery.

Route completion	Deviation from instructions	Criteria definition	Route score
Successful (within time, correct location)	Perfect	Arrive at destination within anticipated time and follow all navigation instruction steps.	3
	Slight deviation	Arrive at destination within time but fail to follow a maximum of 2 instruction steps.	2
Failed (exceed time, incorrect location)	Major deviation	Representing late or incorrect route delivery. Arrive at destination and fail to follow minimum of 3 instruction steps *or* arrive at destination outside of anticipated completion time.	1
	Fail to arrive at destination	Failed to follow > 4 instructions, deviate from route for > 5 min, or self-declaration of inability to complete course. Do not arrive at destination.	0

destination, or in the event of route failure as defined in Table 1. Route completion times represent the duration of a "delivery" from start to finish, including *moving* and *not moving* time. A scoring system was developed to aid comparison of the results based on completion time *and* errors. Anticipated completion times for each route were calculated using the route mapping software based on the route profile and mode of transport (Garmin, 2016).

2.5.2. Safe navigation (RQ2)

2.5.2.1. Hazard perception. The definition of developing hazards from the UK government driving agency i.e. "*A developing hazard is something that would cause you to take action, like changing speed or direction*" (DVLA, 2017) was read to participants at the start of the session and the verbal protocol practiced during a device familiarisation route. Developing hazards are referred to as hazards for the purpose of the study. A strategy reported to determine hazard perception *in simulations* is "*looked but failed to see"* where failure results in a collision (White and Caird, 2010) and is therefore unsuited to real-world use. A real-world hazard perception strategy was developed, and events categorised according to the schemas in Table 2.

2.5.2.2. Device interaction. Both *frequency count* (number of times looking at device) and *duration (*time looking at device) were calculated for the duration of the route and during road or traffic crossings to indicate diverted attention. To determine the area of interest (AOI) for the *in-sight* display, participants were required to read aloud from the device prior to commencing each timed session. The *handheld* (or handlebar mounted) device was visible to the front facing camera and interactions were logged manually in a frame by frame analysis. Definitions used for classification and mark-up of events are presented in Table 3. If the device was not visible in the camera scene, no interaction was marked.

2.5.3. Useable navigation (RQ3)

The usability of any device is a subjective measure, determined by the individual's perception and experience, linked to satisfaction and potential likely future use (Rubin, 1994). The System Usability Scale (SUS) (Brooke, 2013) was utilised for this study. Participants are required to rate the devices using a Likert scale of 1–5, 1 represents strongly disagree, 5 strongly agree and 3 is neutral on completion of their session. Participants were invited to provide additional comments

Table 2
Classification of hazard response behaviour according to both eye movement and verbal acknowledgement.

		Verbally acknowledge hazard	
		Yes	No
Eye glance behaviour (fixation lands on hazard area for 3 frames)	Yes	Correct response indicating situation awareness.	Looked but failed to acknowledge indicating lower situation awareness.
	No	Did not look but acknowledged indicating hazard out of view.	Failed to look, failed to acknowledge indicating lack of situation awareness.

Table 3
Event classification for route, road crossing and device interaction for both Handheld and in-sight displays. Note: 3 frames of video are equivalent to 40–78 ms due to software limitations.

Event name	Start event definition	End event definition
Route	Participant instructed to begin route by facilitator, participant views first instruction.	Participant arrives at destination (successful route completion) or instructed route complete by facilitator (failed route completion)
Road/traffic crossing	Walking *road crossing:* Participant steps into road. Cycling *traffic crossing*: Participant moves out of current road lane toward crossing (no longer riding parallel to curb)	Walking: Participant steps onto pavement. Cycling: Participant returns to correct lane position on new road (returns to riding parallel to curb)
Device interaction for *Handheld*	Gaze marker is located on the device for duration of 3 frames of the replay video	Gaze marker is no longer on the device for duration of 3 frames of the replay video.
Device interaction for *in-sight*	Area of interest is set according to gaze marker activity during participant reading instruction aloud during beginning of session. The software automatically counts interaction frequency and duration.	

regarding whether they were or were not in favour of each device and participant commentary regarding device and navigation issues were transcribed from the eye tracking recordings.

3. Results

The mean gaze sampling recording value (i.e. indicating detection of the eye during the eye tracking recording) across all participants and routes was 76%, minimum 38% and maximum 95%. The data from 24 participants were suitable for inclusion (one female). Self-reported navigation confidence ratings were assessed for potential confounding of results. A 0.139 Pearson's Correlation suggested that navigation confidence produced no confounding effect (Field, 2013). The majority of participants (18) regularly commuted on foot (3 regularly commuted by bicycle) and 4 participants had worked as cycling couriers.

3.1. RQ1: accurate navigation

The majority of routes were completed successfully (61.5% successful completion), representing potential on time deliveries as listed in the results in Table 4. The highest probability of receiving the delivery on time was with the *handheld* device on a simple route with signed roads (100% walking, 91.7% cycling). The highest probability of not receiving a delivery was with the *in-sight* display for cycling on a route without road names (83.3%). There was a higher probability of *receiving* the delivery when the *in-sight* device was used while walking (75%) rather than cycling (47.9%). There was a 43.8% probability that the delivery would be *not received* if using the *in-sight* display.

To illustrate the probability of delivery success or failure, 95% confidence intervals were calculated, shown in Fig. 3. The probability of successful delivery with the *handheld* device was higher (41% ± 10 (31, 51)) than with the *in-sight* device (21% ± 8% (13, 29)). Probability of *failed delivery* was higher using the *in-sight* device (29% ± 9% (20,38) than the *handheld* (9% ± 6% (3,15).

3.2. RQ2: safe navigation

3.2.1. Hazard perception

The total number of hazards encountered for the *handheld* device (n = 158) and *in-sight* display (n = 152) were similar and the results are detailed in Table 5.

The majority of participants correctly responded to hazards using both devices (*handheld* 51% and *in-sight* 56%). Events classified as LBFTA (looked but failed to acknowledge) were higher with the *handheld* device (42%) than the *in-sight* (38%). Both devices had equal percentage occurrence of “failed to look or acknowledge” (6%). The 1% “did not look but acknowledged” occurred when a car approached a participant from behind but did not overtake and was therefore not visible to the eye tracking front facing camera. There were a greater number of hazards encountered walking (187) than cycling (123), with a higher percentage of cycling hazards correctly acknowledged (65% > 46%).

3.2.2. Device interaction

Participants were considered at greater risk of injury whilst crossing streams of traffic. Results are presented for both *not crossing* and *crossing* navigation. During the walking routes participants interacted with devices more frequently (mean fixation count of 126 (± standard error in the mean (SEM) 42)) than whilst cycling (mean fixation count of 76 (± SEM 22)). During road crossings, the *handheld* device was fixated less often (mean count 10.35 (± SEM 2.7) compared with the *in-sight* display (mean count 29.46 (± SEM 6). The *handheld* device was fixated for a smaller percentage of time with reduced interaction during crossing (*not crossing*: 16% (± SEM 2%), *crossing* 12% (± SEM 2%) compared with the *in-sight* device (*not crossing*: 21% (± SEM 2%), *crossing* 21% (± SEM 0.3%). The *in-sight* display was interacted with for a greater percentage of *crossing* time than *not crossing* whilst participants were walking Fig. 4.

The mean fixation durations results are considered to determine how long participants are distracted by the device and are illustrated in Fig. 5. The *handheld* device was interacted with for longer durations per fixation: *crossing*: *handheld* 0.7s (± SEM 0.2s) and *in-sight* 0.2s (± SEM 0.02s), *not crossing*: *handheld* 1s (± SEM 0.16s) and *in-sight* 0.2s (± SEM 0.02s)). There were no incidents of fixation duration over 2 s whilst using the *in-sight* device and the *in-sight* display was not fixated on for longer than 2 s (< 1.1s). The *handheld* device had longest fixations (*not crossing*: 13 counts (< 3.8s), 4 of which occurred whilst cycling (< 3.2s), *crossing*: 5 counts (< 5s) all during walking routes).

3.3. RQ3: useable navigation

The mean SUS rating for the *handheld* device was higher (68.8

Table 4
Route completion accuracy scores per device and route and mode of transport. H = handheld, I–S = in-sight, H–S = handheld simple, I–S–S = in-sight simple, H–C = handheld complex, I–S–C = in-sight complex.

	Cycling				Walking								
Probability of delivery	H–S	I–S–S	H − C	I–S–C	H–S	I–S–S	H − C	I–S–C	Total	C	W	H	I–S
% Successful	91.7	58.3	41.7	0	100	41.7	91.7	66.7	61.5	47.9	75	81.3	41.7
% Late	8.3	16.7	33.3	16.7	0	16.7	8.33	8.3	13.5	18.8	8.3	12.5	14.6
% Do not receive	0	25	25	83.3	0	41.7	0	25	25	33.3	16.7	6.3	43.8

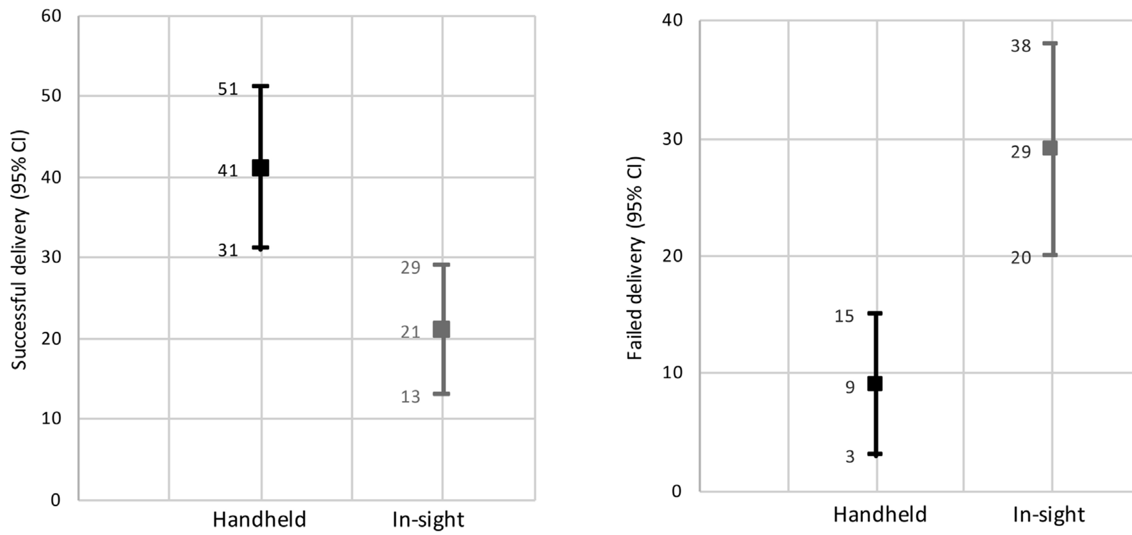

Fig. 3. With 95% Confidence Interval: (Left) Probability of successful delivery, (Right) Probability of failed delivery.

(± SEM 3.3), min. 35, max. 95), compared with the *in-sight* display (52.5 (± SEM 4.1), min. 12.5, max. 92.5). The *handheld* device was awarded a higher usability rating by 19 out of the 24 participants. Twelve participants rated the *handheld* device > 70 usability whereas only 3 rated the *in-sight* device > 70. Participants expressed more confusion, for example "*Have I gone the wrong way? Is it this way?*" or "*I'm struggling to … where is it? When I have to turn?*", whilst navigating using the *in-sight* display (n = 137, 75 cycling, 62 walking) than when using the *handheld* device (n = 51, 34 cycling, 17 walking). There were 38 device issues noted during *in-sight* device use compared with 7 for the *handheld*. The majority of issues (33 out of 45) were caused by the screen display freezing briefly (less than 5 s) and loss of GPS signal. These were resolved within 5 s (automatically by the device, or by the facilitator). One participant was delayed by 15 s due to a disconnect between *in-sight* and GPS signal however the session was completed successfully and within time.

4. Discussion

Navigation accuracy was not optimal with either of the evaluated devices with a chance of successful delivery 41% when using the *handheld* device and only 21% with the *in-sight*. There was less chance of a failed delivery with the *handheld* device (9% ± SD 6%) than with the *in-sight* device (29% ± SD 9%). The visual map on the *handheld* device was observed to help users verify their location relative to the destination prior to formulating their wayfinding plan (Bjerva and Sigurjónsson, 2016). In addition, the visual map allowed participants to adapt their strategy in the event of GPS signal loss and to double check their interpretation of the text instructions and distances. However, the *handheld* device could interfere with the ability to undertake additional manual tasks associated with delivery. For *in-sight* displays there is a need to provide additional contextual information for users to verify their position in the event of GPS signal loss. When the *in-sight* device lost GPS signal or the display stalled, participants expressed frustration and mistrust of the presented data which was a particular issue with the display. The reliability of *in-sight* devices would need to be improved to reduce frustration and errors to be suitable for everyday use by delivery organisations.

A higher percentage of hazards were correctly acknowledged while cycling compared with walking. Whilst walking each participant had acknowledged at least one of the pedestrian's as a hazard when approaching them in their path (i.e. causing them to change direction or speed), however they did not acknowledge *all* of the pedestrians in their paths as hazards. Participants appeared more comfortable interacting with navigation devices more frequently and for longer durations whilst walking. This could be due to the protection afforded by walking on pedestrian only areas or the slower pace of travel. A study comparing walking and cycling in a shared traffic area could help to further clarify the differences. Participants fixated for shorter durations on the *in-sight* display and never for more than 2 s. There were 18 counts of fixations using the *handheld* device that lasted longer than 2 s. This type of gaze behaviour could put the user at greater risk due to diverted attention. These longer fixations tended to occur whilst walking, although the participants are moving at a slower pace they increase their risk of missing visual cues relating to static environmental hazards (Haga et al., 2015) or faster moving traffic when using shared paths. The responses to hazards were similar with both the *in-sight* display (56% correct response, 6% failed response) and the *handheld* device (51% correct response, 6% failed).

According to the SUS rating scales suggested by Bangor et al. (2009), usability results below 70% would require improvement and may not be acceptable to users (Bangor et al., 2009). Users complained

Table 5
Hazard response classification, C = cycling, W = walking, I–S = in-sight, H = handheld. Response to hazards are shown as a % of the total hazards encountered across all participants on the column indicated route combination.

	Handheld All	C–H	W–H	In-sight All	C–I–S	W–I–S	Cycling	Walking
Count of Hazards Total (*mean* ± *SEM*)	158 *(4 ± 0.8)*	61 (1.9 ± 0.2)	97 (2.8 ± 0.3)	152 *(5 ± 0.8)*	62 (2 ± 0.2)	90 (2 ± 0.3)	123 *(2 ± 0.2)*	187 (2 ± *0.4)*
Correct Response (%)	51	62.3	44.3	56	67.7	47.8	65	46
Looked but failed to acknowledge (%)	42	31.1	48.5	38	27.4	44.4	29	47
Did not look, but acknowledged (%)	1	1.6	0	1	1.6	0	2	0
Failed to look or acknowledge (%)	6	4.9	7.2	6	3.2	7.8	4	7

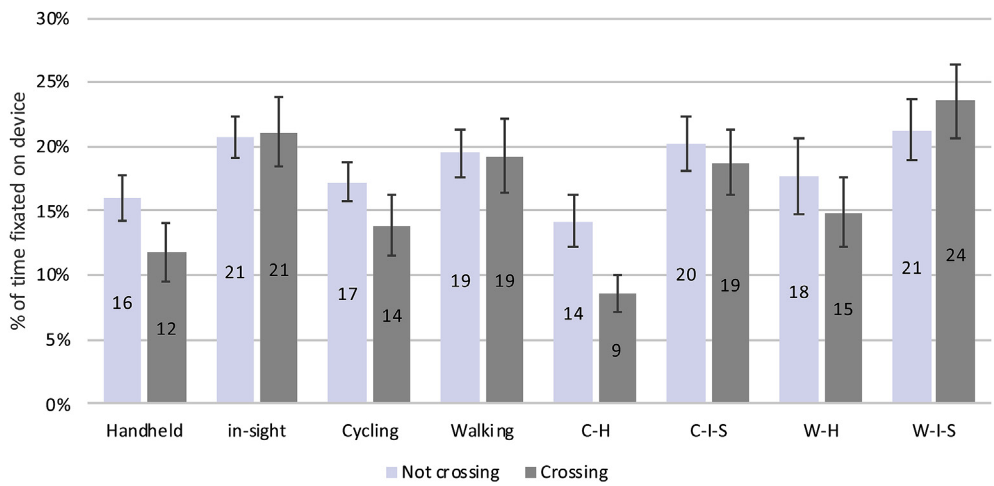

Fig. 4. Mean values and standard error for percentage of time participants fixated on device whilst Not crossing and Crossing. Abbreviations: C = Cycling, W = Walking, H = Handheld, I–S = In-sight.

of eye strain and difficulty focusing when using the *in-sight* monocular device and participants reported feeling *"disconnected from their surroundings"*. The discomfort experienced by participants using the *monocular in-sight* display reiterate the literature recommendations for *binocular* displays to support natural viewing behaviours (Patterson et al., 2006). Feedback regarding the *handheld* device highlighted that "*better (more useable) technology existed in mobile phones*" and participants "*disliked the lack of auditory confirmation*". An extension of the present study will include the use of multi-modal feedback to determine whether the combination of modes indicated in the literature are suitable for cyclist and pedestrian couriers, for example use of haptic and visual (Elliott et al., 2010), or auditory and visual (Jakus et al., 2015). The participants were mobile phone users and hence familiarity with mobile phone navigation aids may have affected their use of the *handheld* unit and influenced usability ratings. However, it is noted that the usability ratings utilised reflect *initial* usability and are not indicative of potential changes over time (Lee and Koubek, 2010). Further research is required to evaluate any change in perceived usability, preference and performance of navigation aids over time.

The results of the present study indicate: (i) the potential use of *in-sight* information to support SA, (ii) a need for navigation aids to provide context and redundant information to aid navigation in the face of signal errors and (iii) reduced obstruction of vision is required for current *in-sight* technologies. A potential variation of a visual navigation display is illustrated in Fig. 6 (b) (to be compared with the in-sight display (Fig. 6 (a)) in which the proposed combination would utilise a small *in-sight* display and a simplified map to allow users to verify the text and arrow instructions against a simple world map.

5. Limitations

Completion times were calculated including *moving* and *not moving* time which provided a *coarse* evaluation of "delivery support" across the routes and resulted in slow average speeds. These combined timings do not support detailed analysis of speed *within* the route nor whether *specific* navigation tasks (for example simple or complex junctions) are more quickly supported by handheld or in-sight devices. Further research is required to explore the effects of device on travel speed and suitability for specific navigation tasks. A detailed study of the effects of device on speed would benefit from additional or redundant tracking of participant speed (e.g. pedometer or cadence based) to verify any GPS data. Prior to commencement of the study sessions, participants were instructed to prioritise safety, follow road rules, and verbalise hazards. It is possible that participants may have exercised higher levels of caution to comply with the request, however this was not evaluated. The use of a *think aloud* or verbalisation protocol can also potentially impact on participants' timed performances (Jaspers et al., 2004), however the verification of both the perceptual and cognitive

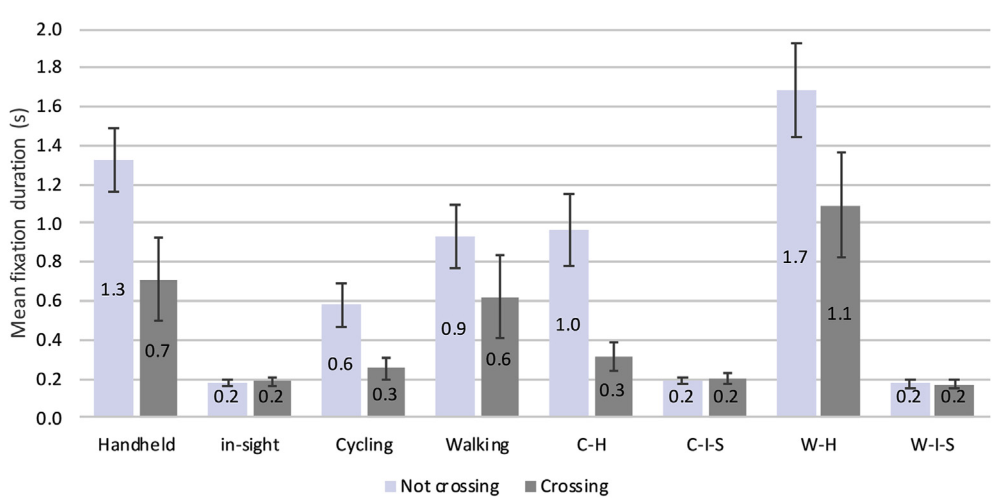

Fig. 5. Mean values and standard error for fixation duration whilst Not crossing and Crossing. Abbreviations: C = Cycling, W = Walking, H = Handheld, I–S = In-sight.

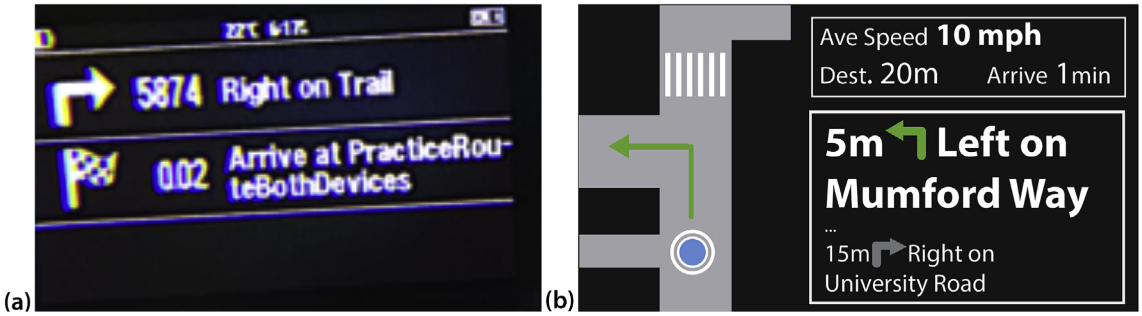

Fig. 6. (a) shows existing instruction in in-sight display, text and basic icons. (b) presents an example of a compact map layout to provide contextual information and redundant verification of instruction.

acknowledgements were adopted as the best indicators of SA with minimal intrusion. Furthermore, learning styles and instructional preferences of the users were not considered and could potentially have influenced users' responses to the instructions (Honey, P., Mumford, 1986). The limited available literature indicates that couriers tended to be young (age 18–25) healthy male students working part time (Maes and Vanelslander, 2012; Ainsley and Cycling Plus, 2013), however an increasing number of female cyclists operating as couriers will affect this demographic. The relatively small sample size (n = 24) and low number of female participants (n = 1) limit the generalisability of the results of this study and further evaluation with a larger demographic is planned.

The study was conducted in ideal weather conditions (i.e. dry days and during daylight hours) and a useful extension of the work presented here would be to consider a wider range of weather conditions to determine how this affects the suitability of the devices and their limitations e.g. the impact of raining, snow and foggy conditions on either the interactions with the couriers or the visibility of landmarks. Lastly, the study was conducted in the real world and as a result each participant experienced a different number of emerging hazards, a controlled environment (for example a closed campus) could be set up to allow for real world navigation with actors used to control the emerging hazards.

6. Conclusions

To support next generation supply chains, the last and first miles of deliveries must be optimised. The human component of logistics activities needs to be supported for both navigation accuracy and safety. The research outlined in this paper has evaluated the capabilities of two representative "state of the art" visual displays in *handheld* and *in-sight* formats considering the need for accurate, safe and useable navigation. The results indicate that the *handheld* device with a map supports accurate and useable navigation. In spite of the fact that *in-sight* displays and *augmented reality* solutions providers propose that the information is contextualised through positioning in the line of sight (Tönnis et al., 2008) the results of this study indicate that users may require *additional confirmation* before they are able to interpret simplified instructions.

The limitations and reliability of GPS connections reduced the benefit of real time position feedback and additional positioning methods may be required for optimised real-time tracking of first and last mile couriers, for example supplementary systems using Radio Frequency Identification (RFID), Wireless local area networks (WLAN) or vision analysis (Li et al., 2016). In this research several participants indicated that the adoption of any alternative devices would require that they provide better performance than an existing standard mobile phone and that any wearables should be both unrestrictive (especially vision), comfortable (not heavy) and affordable (within budget).

In conclusion this study has presented a first step toward optimising the support of the human courier as part of Industry 4.0 supply chain (i.e. Courier 4.0) and has considered both the safety of the user and the accuracy of the task performance as critical components of this process. Further work considering both safe and accurate behaviours in Industry 4.0 workers within factories has been recommended toward improved processes and supply chain networks.

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