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Where do we go from here? An assessment of navigation performance using a compass versus a GPS unit

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ABSTRACT

The Global Positioning System (GPS) looks set to replace the traditional map and compass for navigation tasks in military and civil domains. However, we may ask whether GPS has a real performance advantage over traditional methods. We present an exploratory study using a waypoint plotting task to compare the standard magnetic compass against a military GPS unit, for both expert and non-expert navigators. Whilst performance times were generally longer in setting up the GPS unit, once navigation was underway the GPS was more efficient than the compass. For medium- to long-term missions, this means that GPS could offer significant performance benefits, although the compass remains superior for shorter missions. Notwithstanding the performance times, significantly more errors, and more serious errors, occurred when using the compass. Overall, then, the GPS offers some clear advantages, especially for non-expert users. Nonetheless, concerns over the development of cognitive maps remain when using GPS technologies.

KEYWORDS: navigation performance, wayfinding, map, compass, GPS

1. INTRODUCTION

"…GPS will do to the compass what the computer did to typewriters – make them obsolete." (Guerrero 2004, p. 44)

The ability to navigate one's environment – that is, wayfinding – is a fundamental human survival skill. Nowhere is this more true than in the military domain, where a misunderstanding of position can result in loss of life from either enemy or friendly fire. Issuing soldiers with basic navigation skills and tools is therefore essential to the operational effectiveness of every unit. The products used for navigation in the UK Armed Forces at present are maps, compass, and GPS units. As handheld GPS units become ever more affordable and accessible, the technology represents a direct rival for the traditional map and compass in the military and elsewhere (Guerrero 2004). For the potential benefits of this new technology to be realised, though, it needs to demonstrably improve navigation performance across a range of users, tasks, and environments. In military operations, navigation decisions during are often made under extreme physical and environmental conditions, with inexorable time constraints, and often under fire. As such, soldiers must be highly adept at the task and their tools must be efficient.

A taxonomy of navigation tools has been proposed by Chen and Stanney (1999). The first category comprises tools which display one's current position. In the second category, tools can display current orientation, while those in the third category can log one's movements. Tools in category four can demonstrate the surrounding environment, while the fifth and final category consists of guided navigational systems. In the present context, a compass is an example of a tool in the second category, the map is in category four, while a GPS receiver covers all of the first three categories (and a GPS combined with a moving-map display would offer all five capabilities). From this perspective, GPS technologies appear to offer considerable advantages over the map and compass. Furthermore, this taxonomy does not acknowledge the added capability of GPS-based digital maps to define waypoints and program routes in advance. Such a facility allows 'virtual navigation' and can further alleviate the demands on the navigator as well as potentially reducing the possibilities of error.

Previous opinion on the relative benefits of GPS is mixed. In favouring GPS, Chen and Stanney (1999) suggest that maps are not always the most effective tool – for instance, giving verbal directions to drivers results in lower reaction times and fewer errors than using a map. In fact, map-reading is the most cognitively demanding level of navigation (Foo et al. 2005), as it is based on a world-centred representation of the environment, as opposed to the ego-centred viewpoint of normal locomotor guidance (Chen and Stanney 1999). Using a map to navigate can therefore cause problems of mental rotation when we try to translate the world-centred frame of reference into an internal cognitive map. Our wayfinding abilities are very much dependent on developing these internal representations of the world (Boer and Hirase 2000), but because forming them is a complex process and prone to errors, Foo et al. (2005) conclude that people will usually rely on the simplest navigation strategy available. Moving-map displays or virtual navigation tools can help by providing ego-centred or even orientation-free representations (Arthur and Hancock 2001, Williams 1999). As with any technological support system, then, GPS devices could potentially open wayfinding tasks to a new population of novice navigators. On the other hand, Chen and Stanney (1999) caution that whilst the use of enhanced navigational tools (such as a GPS device) can streamline the wayfinding process, the lack of cognitive involvement can mean that this is at the expense of developing an accurate cognitive map. This echoes the concern that users can become dependent on GPS equipment to the detriment of their basic navigation skills (St. George and Nendick 1997).

In the specific case of military navigation, which is typically off-road and out of sight of landmarks, the potential advantages of a digital map are enhanced. Since there are fewer external cues to position or orientation, the GPS unit can offer a shortcut for building these elements into the cognitive map. Leggatt and Noyes (2000) found that in an armoured vehicle, the best situation for overall workload and performance was for the commander (i.e., navigator) and the driver each to have access to a digital map display. For foot soldiers, Wesler et al. (1998) found a helmet-mounted display to be superior for navigation accuracy than either a traditional map, compass, or even a GPS. On the other hand, a pilot study by Stanton et al. (2005) found traditional command and control techniques (using a paper map and radio communications) to be slightly, though nonsignificantly, quicker on overall mission time than a new ‘command wall’ (involving a computer generated 3D map with live position updates of the team and advanced communication technology). However, this was a simulated urban military reconnaissance scenario, rather than a navigation task, with the objective to collect data on hostile and friendly forces in the environment. The results may therefore have been more attributable to the communications technology, rather than the map representation. Indeed, their data suggested that with more than one unit in the field, the command wall actually increased efficiency, as the voice communications bottleneck was avoided.

Overall, then, we see that both traditional techniques and GPS technologies have pros and cons for navigation – both generically and specifically in the military domain. Paper maps are certainly light, informative, and have no external power needs – but are limited to providing information about the surrounding environment only. In a stressful fire situation, the extra workload of interpreting the map can lead to errors (Leggatt and Noyes 2000). GPS can reduce such demands by adding position and orientation information, and circumvents any issues of orientation, but perhaps diminishes the development of cognitive maps. Since the evidence to choose between them is equivocal, in the present study we directly compare the effectiveness of an army-issue GPS receiver against the military standard compass in a basic waypoint plotting task. Given the potential implications for user skill discussed above, experience was varied as an independent variable whilst tasks and environment were held constant. The primary objective of the study is to determine what, if any, trade-offs in performance might ensue, particularly in terms of navigation efficiency and errors in wayfinding.

2. METHOD

2.1. Design and Procedure

This study investigates the two principal methods of navigation used within the British Army – navigation with a standard compass, and navigation with the aid of a GPS unit. Both methods are used in conjunction with standard Ordnance Survey maps. In the British Army, GPS units are only issued to commanders from section level upwards. If there are clear benefits of GPS units, though, particularly for novice users, there may be justification for replacing the compass across the ranks. Thus we also manipulated navigator skill in a mixed within- and between-subjects design, with level of expertise as the between-subjects independent variable (two levels), and product type the within-subjects variable (GPS vs. compass). Task time and errors were the dependent variables.

In a related study on vehicle navigation (Antin et al. 1990), the task was divided into route preparation, and actual navigation. In the present experiment, the task was similarly divided into preparation and waypoint plotting. Preparing the compass involved the sub-tasks of validating the compass, orientating the map to the ground, determining current position, and marking the destination on the map. Preparing the GPS entailed acquisition of the satellite signals, accessing the 'setup' option, and adjusting settings to reflect current location (i.e., 24 hour clock to GMT, British grid, Ordnance Survey GB, metric units and magnetic north). Although the task execution method was very different between the two tools, dividing the task in this way allows us to make more relevant comparisons on a common set of goals for each group – the performance measures are goal-based rather than task-based.

Given the logistical and ethical implications of conducting the study in a realistic military environment, the task itself was conducted as a desktop problem rather than a real-world exercise. This decision had the added benefit of facilitating experimental control – not only are we limiting environmental effects, but by holding task and environment constant, we can focus on the effects of user skill. Participants were required to evaluate a series of waypoints on a map using traditional compass methods or the relevant function with the GPS. With the compass, this divided into deciding a suitable route marking the waypoints on the map, measuring distance of next leg using scales, taking a map bearing for the next leg, and translating the map bearing into a real world bearing. The GPS equivalent tasks were deciding the route and entering the waypoint into the GPS unit, creating a route in the GPS unit, activating the GPS route, and accessing the navigation page.

Participants were given 15 minutes teaching and practice time with instruction manuals prior to the experimental tasks. Two experimental trials with each method were then conducted, with the order of conditions (GPS or compass) counterbalanced across participants.

2.2. Apparatus

The products under test in this study are equivalent to the standard military issue. The magnetic compass was the Silva type 4 model. The GPS units currently used by the British Army are made by Garmin, and the model used here was the Geko 201. This is a model styled for civilian use, so details such as colour will be different from military models, but it has the same number of controls and the same menu systems as the military version. The map used was the Ordnance Survey Landranger 186, Aldershot & Guildford, 1:50000 scale.

2.3. Participants

Ideally the experiment would have used actual soldiers as participants, but the practical difficulties in gaining access to serving military meant we recruited civilians instead. Nonetheless, the sample was stratified to be representative of an infantry population – that is, an exclusively young male sample (N = 23, aged 16 to 24). Of these, 15 participants were classified as non-expert, and eight as expert users. For the purposes of this study, ‘expertise’ was defined in terms of formal instruction in methods of navigation, and some familiarity with the products under test.

3. RESULTS

3.1. Performance times

Table 1a: Mean total performance times (seconds) for preparation with compass and GPS

	Compass – T1	Compass – T2	GPS – T1	GPS – T2
Non-expert	528	516	1059	1033
Expert	321	334	823	723

Table 1b: Mean total performance times (seconds) for navigation with compass and GPS

	Compass – T1	Compass – T2	GPS – T1	GPS – T2
Non-expert	433	404	178	168
Expert	135	154	50	46

Tables 1a and 1b detail the mean total performance times for preparation and waypoint plotting, with compass and with GPS, across the two trial runs. These data were analysed using a series of repeated measures Analysis of Variance (ANOVA) tests, separated according to navigation type, task type and trial, and with expertise as a between-subjects factor. For brevity and clarity, only the significant comparisons will be detailed here; all other tests were nonsignificant.

There were significant main effects of expertise for preparing the compass ($F(1, 21) = 48.0$, $p < 0.001$), preparing the GPS ($F(1, 21) = 311.1$, $p < 0.001$), navigating with the compass ($F(1, 21) = 1003.5$, $p < 0.001$), and navigating with the

GPS ($F(1, 21) = 261.2$, $p < 0.001$). Clearly, expertise was a successful manipulation with experts performing more quickly than non-experts across the board.

There was also a significant effect of trial for preparing the GPS ($F(1, 21) = 5.85$, $p < 0.05$). GPS preparation was achieved more quickly on the second trial, most likely the result of a practice effect with the unit.

A significant interaction was observed for trial by expertise when plotting with the compass ($F(1, 21) = 4.90$, $p < 0.05$). Whilst performance times for non-experts remained fairly constant across trials, those for experts increased slightly on trial 2.

Comparing between the navigation tools, GPS was slower to prepare than the compass in both trial 1 ($F(1, 21) = 467.1$, $p < 0.001$) and trial 2 ($F(1, 21) = 556.3$, $p < 0.001$). Moreover, there was a significant interaction between expertise and navigation method on trial 2 ($F(1, 21) = 5.14$, $p < 0.05$). A visual inspection of the data suggests that with practice, the benefits of expertise are more apparent when preparing the GPS than for the compass.

For the waypoint plotting task, GPS was now quicker than the compass method on both trial 1 ($F(1, 21) = 456.4$, $p < 0.001$) and trial 2 ($F(1, 21) = 360.3$, $p < 0.001$). There were also interaction effects on both trials ($F(1, 21) = 95.6$, $p < 0.001$ at trial 1; $F(1, 21) = 39.8$, $p < 0.001$ at trial 2). Now it seems that GPS is an aid for non-experts, as the performance differences across levels of expertise are far narrower when using GPS than when using the compass.

3.2. Errors

Table 2a: Total number of errors in preparation for compass and GPS

	Compass – T1	Compass – T2	GPS – T1	GPS – T2
Non-expert	148	83	63	22
Expert	10	6	11	8

Table 2b: Total number of errors in navigation for compass and GPS

	Compass – T1	Compass – T2	GPS – T1	GPS – T2
Non-expert	65	24	35	20
Expert	7	5	2	3

Tables 2a and 2b show the total frequency of errors across each of the conditions. A qualitative analysis of the error types involved revealed that a considerable proportion of the errors with GPS were due to interface issues (rather than fundamental navigation errors), and this was particularly true for expert users. Such errors were mostly recoverable and did not seriously affect the waypoint plotting task. When using the compass, however, most of the errors did lead to problems of actual navigation.

A chi-square analysis of these data was significant for preparation (*chi-square*(3) = 14.7, $p < 0.005$), but surprisingly not for waypoint plotting (*chi-square*(3) = 2.62, $p = 0.46$). An analysis of the residuals and the graph in figure 1 suggests that the source of the result for preparation lay primarily with the non-experts' errors, particularly in preparing the compass on the first trial.

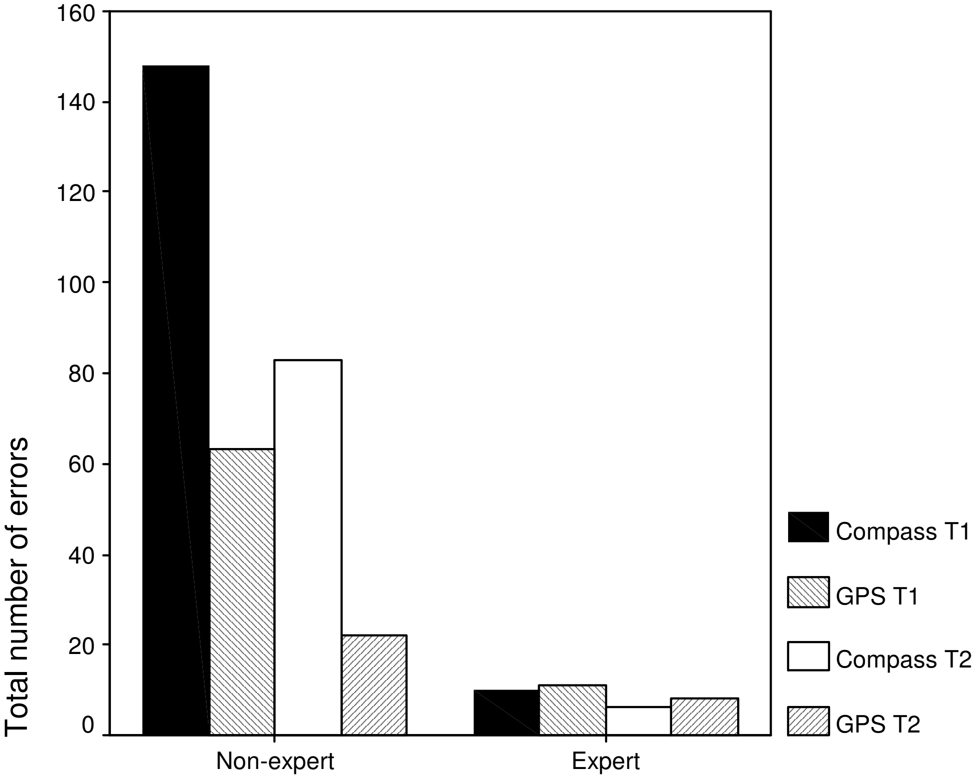

Figure 1: Error frequencies for preparation task

4. DISCUSSION

The present study explored whether GPS offers benefits over a standard compass in both errors and performance times. On the whole, expertise in navigation was a far greater determinant of performance than the navigational tool used. Nonetheless, the relative advantages of the compass and the GPS unit did become apparent when we considered the task context in more detail.

In task preparation, the GPS unit actually took longer to set up than the compass. Although most of this effect was undoubtedly due to the GPS acquisition of satellite signals, the fact that experts tended to be quicker than non-experts suggests that the preparation task is inherently more difficult than with the compass. Since the expertise manipulation was at a more general level of navigation skills, these results imply that the technicalities and terminology of navigation are less intuitive when using the GPS unit. Interestingly, then, in this case the GPS does not offer the usual benefits of such technological support systems.

However, the GPS did lead to faster waypoint plotting performance for both experts and non-experts, thus compensating for the initial deficit overall. Indeed, non-experts seem to catch up with experts when using the GPS compared to their performance times with the compass. This suggests that the wayfinding task was easier with the GPS unit, which is more consistent with typical expectations about technology and automation as it takes over many of the calculation and orientation tasks previously carried out by the human. For military users, this could have potential benefits in the stress of a real situation under fire, when the more difficult compass task could lead to overload and errors (cf. Leggatt and Noyes 2000).

Given the differences in performance times for preparation and wayfinding, there is clearly an optimum length of mission at which point the GPS efficiencies in wayfinding outweigh the longer preparation times. Although the present experiment used a desktop task, we can derive some figures to estimate the point during a real navigation mission at which a GPS user would overtake the compass navigator. For experts, after around 17 minutes of desktop plotting and five waypoints, the GPS becomes more efficient overall. Let's call this 'navigation time', and assume that a navigator in the field would be stationary while making these calculations. Now we add in some hypothetical figures for a live field navigation task – in terms of distance and actual walking time the average leg walked between waypoints is between 500m and 1km. Walking at a tactical advance speed of 4km/h we can assume an average time of 15 minutes for each waypoint for ease of calculation. Thus, for traversing five waypoints (5x15 = 75 minutes) plus 17 minutes of navigation time, after a total of one hour and 32 minutes in the field the GPS unit saves time in the hands of the expert user. Missions shorter than this time would be more efficient with a compass. The equivalent calculation for non-expert users reveals that GPS begins to save time after nine waypoints, or one hour and three minutes of navigation time. Adding in the walking time means that overall time spent in the field is three hours 18 minutes before the GPS user overtakes the compass navigator.

So, these performance times do not necessarily support the argument for providing all soldiers with GPS on the basis of helping the less experienced navigators. Working on the assumption that a typical patrol mission may only last between one and two hours, an unprepared GPS unit is no more efficient than a compass for expert users, and for novices it is in fact faster to use a compass. If, however, the preparation stages have been completed beforehand, then GPS is immediately more efficient for both groups. Since much of this preparation time probably does not require the operator's attention (i.e., in acquiring the satellites), the preparation task could be built into military procedures in advance of the mission. Similarly, long-term navigation operations would also demonstrate a clear benefit from using GPS.

These benefits are further reinforced by the lower numbers of errors observed when preparing the GPS unit. Whilst expert users made very few errors overall, non-expert navigators exhibited superior performance with the GPS, and over the course of just two trials almost equalled expert performance with regard to errors. Moreover, many of these errors were just slips on the interface, whereas with the compass there were more fundamental mistakes in navigation. Overall, then, GPS wayfinding will be more accurate and more likely to succeed than when using the compass.

Whilst we would like to emphasise that this was an exploratory study, the results indicate that GPS can improve performance over simple wayfinding with a compass – though the specific advantages are context-dependent. Non-expert navigators can particularly benefit if the mission is long, or if accuracy in navigation is required. Experienced navigators can also be more efficient on long missions, and may find the GPS task easier to cope with in stressful situations. This could explain why Antin et al. (1990) found that, in contrast to our results, drivers spent longer preparing their route with a paper map, but then less time on navigating during the drive than with a GPS. Such behavioural preferences are probably due to the relative task difficulty – drivers are unwilling to accept the added stress of using a paper map while driving. These conclusions are supported by Leggatt and Noyes (2000), who demonstrated clear benefits for using digital maps in a military vehicle-based study.

The downside to these benefits, though, is that the human inevitably becomes less skilled in such tasks (cf. Bainbridge 1983), and could become over-reliant on GPS (St. George and Nendick 1997). As a case in point, Williams (1999) found that pilots tended to prefer a GPS display at the expense of the existing aircraft navigation instruments. Furthermore, there is also the concern that such 'virtual navigation' can degrade memory for the route and the user's cognitive map (Chen and Stanney 1999, Ruddle 2001). In a slightly different task which involved military reconnaissance, Stanton et al. (2005) did find slight performance benefits for a paper map. If navigation skills or internal representations are affected, it could cause problems if the GPS unit fails. Future research could extend the present experimental design to cover observations of a real-world navigation task (as opposed to a desktop exercise), taking measures of workload, trust, situation awareness, and the development and quality of cognitive maps. To test the effectiveness of the cognitive map, participants could be asked to find their way 'home' without using the tools. Where the present study essentially used GPS as a replacement compass, further work could evaluate the effectiveness of a fully GPS-enabled moving-map display, thus truly accounting for all five categories in Chen and Stanney's (1999) taxonomy of navigational tools. Such a system could even help foster cognitive maps, and hence eliminate that drawback of GPS tools. In the meantime, though, it seems that the compass is not quite ready to be condemned to obsolescence.

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