

Effects of task load and cognitive abilities on performance and subjective mental workload in a tracking task

Susana Rubio-Valdehita^{1*}, Eva María Díaz-Ramiro¹, Ramón López-Higes² y Jesús Martín-García¹

¹Departamento de Personalidad, Evaluación y Tratamientos Psicológicos II: Psicología Diferencial y del Trabajo

² Departamento de Psicología Básica II: Procesos Cognitivos

Título: Efectos de la carga de tarea y las capacidades cognitivas sobre el rendimiento y la carga mental subjetiva de una tarea de seguimiento.

Resumen: El objetivo de esta investigación fue determinar los efectos del nivel de inteligencia general y del perfil aptitudinal de los individuos sobre el rendimiento y las evaluaciones subjetivas de carga mental de una tarea de seguimiento. A pesar de que la mayoría de los autores señalan que la carga mental depende tanto de las características de la tarea como de la capacidad de los individuos, la investigación dirigida a determinar la influencia real de los factores de diferencias individuales es muy escasa. En este estudio se recogieron medidas del rendimiento y de la carga mental subjetiva en una tarea de seguimiento con diferentes niveles de dificultad. Los resultados mostraron efectos significativos, simples y de interacción, de los factores de complejidad de la tarea tanto sobre el rendimiento como sobre la carga mental subjetiva. La aptitud espacial fue la que mostró un mayor efecto mediador, particularmente sobre la carga mental. Los sujetos con un mayor nivel aptitudinal registraron evaluaciones de carga mental más elevadas que los menos aptos, independientemente del instrumento utilizado para medir la carga mental. Finalmente, los sujetos más aptos alcanzaron niveles de rendimiento más altos que los menos aptos, especialmente en la condición de seguimiento más difícil.

Palabras clave: Carga mental subjetiva; capacidades cognitivas; tarea de seguimiento; rendimiento.

Abstract: The aim of this study was to determine the effects that the level of general intelligence and the aptitude profile of individuals have on performance and subjective assessments of the mental workload involved in carrying out a tracking task. Although all authors acknowledge that mental workload depends both on the characteristics of the task and the ability of individuals to perform it, little research into the real influence of these individual difference factors has been carried out. The subjects' performance and mental workload when carrying out a tracking task with different levels of difficulty were measured. Both simple effects and those relating to the interaction of the two task complexity factors were shown to have significant effects on performance and subjective mental load. Spatial aptitude was shown to have the greatest mediating effect, particularly on mental workload. Surprisingly, the subjects with the greatest ability reported higher mental workload assessments than those less able, irrespective of the instrument used to measure the workload. Finally, the subjects with greater ability achieved higher levels of performance than those less able, particularly in the more difficult tracking task.

Key words: Subjective mental workload; cognitive abilities; tracking task; performance.

Introduction

Testing mental workload has become a key factor in developing work systems designed to provide greater levels of comfort, satisfaction, efficacy and safety. Choosing the correct design for a task depends not only on the level of performance or efficacy achieved but also on the mental workload of the worker involved in the task (Pretorius and Cilliers, 2007; Hancock and Meshkati, 1988).

Generally speaking, mental workload is defined as the difference between the individual's ability and the demands of the task or tasks he or she must perform. Thus, a work overload is said to exist when the demands of the job exceed the capacity of the worker involved. If, on the other hand, the ability of the worker exceeds the demands of the job he or she is said to have residual capacity which can be used for additional tasks (Boles, Bursk, Phillips and Perdelwitz, 2007; O'Donnell and Eggemeier, 1986; Wickens, 2008). In this sense, for example Hart and Staveland (1988) defined the mental workload as the result of the interaction between the requirements of the task, the circumstances under which it is executed and skills, behaviour and perceptions of the operator. O'Donnell and Eggemeier (1986), Gopher and Donchin (1986) or Meshkati (1988) are other examples of researchers who recognize the impor-

tance of individual differences as factors involved in the mental workload. In his model, Meshkati (1988) includes, among the characteristics of the operator which act as moderating variables the cognitive abilities of the individual, motivational aspects, goals, attitude toward the task and toward the usefulness of the results, training and previous experience, cognitive complexity, styles of decision, sensorial capabilities, level of activation, etc. In a similar way, but more recently, Young and Stanton (2001, 2002) defined the mental workload of a task as "the level of attentional resources required to meet both objective and subjective performance criteria, which may be mediated by task demands, external support, and past experience" (p.1019).

In the light of the above definition of mental workload it is evident that there are two factors involved. First, work effort will increase according to the complexity of the task and its structural characteristics. Secondly, certain individual differences can make an individual feel more or less burdened, and this will depend on his or her personal characteristics. Nevertheless, research in this field has traditionally focussed on the first factor, analysing the level of mental workload associated with different task configurations; few studies have focussed on analysing the effects that individual differences have on mental workload assessments. Research has usually considered mental workload to be a variable depending solely on the task. As a rule, the effects of mental workload on subject performance are analysed, modifying the degree of complexity of the task, introducing additional tasks or reducing the time available for completing the task. It is easy

* Dirección para correspondencia [Correspondence address]: Susana Rubio Valdehita. Facultad de Psicología. Universidad Complutense de Madrid Campus de Somosaguas. 28223. Pozuelo de Alarcón. Madrid. (Spain). E-mail: rubiova@psi.ucm.es

to find a great amount of studies on the effects of the complexity of a task on subjective mental workload and/or on the subjects' performance (for example, Hancock, Williams, Miyake and Manning, 1995; Morris and Leung, 2006; Rubio, 1993; Vitense, Jacko and Emery, 2003). The main conclusion of these studies was that as the complexity of the task or tasks increases performance deteriorates and the levels of subjective mental workload increase (see Warm, Matthews and Finomore (2008) for a description of a variety of studies that found a negative relation between performance and subjective mental workload in vigilance tasks).

There are also a number of studies which examine the effect of individual differences on performance (for example, Miyake, Loslever and Hancock, 2001; Rubio, 1992). The chapter of Johnson and Proctor (2004) dedicated to individual differences in attention includes a review of studies that found significant effects of intelligence on performance on a variety of tasks.

However, although most researchers acknowledge that mental workload depends on multiple factors relating as much to the task in hand as to the characteristics of the subjects involved (Crutchfield and Rosenberg, 2007; Recarte, Perez, Conchillo and Nunes, 2008; Welford, 1978), there are few studies where mental workload is examined as a dependent variable of the individual's cognitive ability (Gonzalez, 2005). In this regard, Bunce and Sisa (2002) analysed the effects of age on subjective mental workload measured by the NASA-TLX during the course of a vigil and how do workload perceptions relate to performance on a vigilance task. They showed a certain interest, albeit indirect, in studying the effects of this type of characteristic on subjective estimations of mental workload when they discussed the deterioration of cognitive ability resulting from aging. The results obtained led them to conclude that although age had no effect on performance, it did have a significant effect on mental workload. In this respect, younger subjects showed significantly higher levels of frustration and temporal demand. Although the age main effect was nonsignificant for the weighted workload index, younger participants perceived more workload than older subjects. For the rest of the NASA-TLX dimensions, younger individuals perceived greater mental demand and effort; while older participants experienced more physical demand and performance, although these differences did not result statistically significant. However, when the effect of test-time was introduced, age-related differences were found in relation to increases in mental, temporal and physical demands and frustration level, as the vigil progresses. The differences between pre-test and post-test measures of workload were greater for older than younger participants. Previously, Deaton and Parasuraman (1993) had also studied perceived mental workload in the context of age differences affecting vigilance, and found that although there were no significant effects on the subjects' performance, significant effects were found in subjective mental workload assessments.

In recent years have appeared studies that try to incorporate the role of knowledge and skills of operators in the prediction of the mental workload (Legree et al., 2003; Taylor et al., 2005, Xie and Salvendy 2000). According to these authors, is a priority the identification of the cognitive, emotional and interpersonal characteristics that determine the adjustment between the operator and the task undertaken and affecting the effective management of processing resources.

In the light of the above considerations, we designed an experiment aimed at analysing the effects of the general standard of intelligence and aptitude profile of individuals on performance and subjective assessments of mental workload involved in performing a tracking task. Our study is based in the assumption that subject's cognitive abilities have an influence on performance and subjective mental workload. This hypothesis is based on the results obtained in several studies that have demonstrated that performance in a variety of attentional tasks and intelligence are positively related (Ackerman, 1988; Tuholski, Engle and Baylis, 2001; Ben-Shakhar and Sheffer, 2001). As Johnson and Proctor (2004) pointed out more intelligent individuals are better at performing task requiring attention. Intelligence is associated with a great variety of attentional tasks, especially tasks that require controlled attention or active maintenance of goals. Among all cognitive aptitudes considered those more directly demanded by the tracking task (non verbal intelligence and spatial aptitude) will be the most important. Although ISO 10075 pointed out as individual factors that could to mediate the stress-strain relationship on mental workload subject's abilities, skills, knowledge, and experience, it doesn't explain the direction or the strength with which these variables influence mental workload. In this sense and taking account, also, the studies mentioned above that found a negative relation between performance and mental workload, our prediction is that as the subject's cognitive abilities increase subjective mental workload will be reduced and the performance will be higher.

Method

Participants

The study was performed on 106 right-handed subjects studying psychology at the Complutense University of Madrid, of which 85 were women and 21 men. The age of the participants ranged between 19 and 27 years of age, with a mean of 21.27 and a standard deviation of 1.57 years. All subjects took part voluntarily in this experiment.

Variables and design

An experiment was designed in which the subjects had to perform a tracking task whose complexity varied according to two within-subjects variables: a.) path width (wide vs. narrow) and b.) task condition (single vs. dual). In the dual task condition participants had to perform a memory task at the same time as they performed the tracking task. The de-

pendent variables used included measurements of the subjects' performance in the tracking task and the subjective mental workload. To measure subjective mental workload three instruments were used: NASA-TLX (Task Load Index), SWAT (Subjective Workload Assessment Technique), and WP (Workload Profile). The total sample was divided into three groups, each of them using a different instrument. The sample size of each group was as follow: 36 subjects used NASA-TLX, 35 used SWAT and 35 used WP. The intelligence level and aptitude profile of the subjects involved in the experiment were also measured.

Task

- a. *Single task.* In the tracking task the subject task was maintaining the cursor within a moving reference path by using the left-right cursor keys on the keyboard. The width of the path was established as the parameter of objective difficulty: the narrow (50 pixels) was the difficult level and the wide (70 pixels) the easy one. Subjects performed this task using their right hand. Performance was measured based on the percentage of time spent correctly following the path. The duration of each of the single tasks was 45 seconds.
- b. *Dual task.* A memory search task was introduced as additional task with the sole aim of increasing complexity. The memory search task required to subjects to memorise a set of alphabet consonants at the start. Then, a letter was displayed to the subject, who had to respond whether or not the letter shown matched with one of the letters previously memorised. All the letters were chosen at random by the computer program. The subject responded by pressing the F1 key with the left hand if the answer was affirmative, and F2 if not. The tracking task was displayed on the right side of the screen and the memory task on the left, being close enough to minimise the concurrence cost. The subjects received instructions to pay the same attention to both tasks and perform them both to the best of their ability. To ensure that the subjects were concentrated on both tasks, the program included a visual warning message displayed on the screen when answers to the memory task were delayed more than 10 seconds or when the cursor strayed from the reference path in the tracking task. As the single versions, the duration of each of the dual tasks was 45 seconds.

The tasks used demanded visual, manual and spatial resources (Rubio et al., 2004, Wickens, 1984).

Equipment

Pentium MMX personal computers, 200MHz, 64 Mb RAM with SuperVGA 0.28 non-interlaced monitors were used for running the experimental tasks and gathering the performance data.

Instruments

Measurement of subjects' factorial and general intelligence

The Factorial and General Intelligence (IGF) test developed by Yuste (1997) was used to measure subjects' general and factorial intelligence. According to the author, this test enables good discrimination between extreme levels of population distribution of the intelligence variable. The IGF test measures the following seven factors: general intelligence, non-verbal intelligence, verbal intelligence, abstract reasoning, spatial aptitude, verbal reasoning and numerical skill. Non-verbal intelligence is composed of abstract reasoning and spatial aptitude. Verbal intelligence is composed of verbal reasoning and numerical skill. The general intelligence score is obtained as the mean of verbal and non-verbal intelligence. The psychometric properties of the IGF have been object of a vast research developed by its author, showing high validity and reliability coefficients. The reliability was analyzed using the KR-20 coefficient of Kuder-Richardson, obtaining values from 0.70 to 0.92. The construct validity of IGF was demonstrated by means of factorial techniques. Correlations between IGF and other intelligence tests shown high concurrent validity (coefficient values from 0.31 to 0.62 with Raven; from 0.48 to 0.79 with Otis; from 0.38 to 0.72 with Domino tests).

Assessment of subjective mental workload

The three instruments used were SWAT, NASA-TLX, and Workload Profile (WP). The reason for using different instruments is because data presented here formed part of a research in which the main goal was to compare their psychometric properties.

- a. *Subjective Workload Assessment Technique (SWAT).* This technique, developed by Reid's research group (Reid et al., 1981, 1982), uses conjoint measurement for analysing data. It assumes that the mental workload of a particular task or activity is determined by three factors or dimensions which the authors call time, mental effort and stress. Each dimension is assessed on a three point scale with verbal descriptions. SWAT is applied in two stages: (1) the first stage takes place prior to performing the experimental task and yields the load scale by using conjoint measurement to analyse the subjects' arrangement of 27 possible combinations (3 time levels x three mental load effort levels x three stress levels) and (2) a second stage immediately following the first in which subjects assess the mental workload of each task by rating it as 1, 2 or 3 in each of the three dimensions. These assessments are transformed into an overall effort score by applying the scale developed in the previous stage.
- b. *NASA – Task Load Index (TLX).* This procedure was developed by Hart and Staveland (1988) and identifies the following six mental workload dimensions: mental demand, physical demand, temporal demand, perform-

ance, effort and frustration level. The procedure is applied in two stages: (1) the first stage takes place prior to performing the experimental task and yields the load scale from the 15 binary comparisons of the six dimensions, choosing from each pair the one which the subject perceives as being the greatest source of effort, and (2) a second stage immediately following the first in which subjects assess the mental workload of the task on a scale of 0 to 100 (divided into groups of 5 units) based on each of the six dimensions. The data yielded from both stages is used to assign the overall mental workload involved in the task by applying the following equation:

$$IC = \sum p_i X_i / 15$$

Where p_i is the initial load of each dimension and X_i is the assessment given to each dimension.

Several studies reported that NASA-TLX was a valid, sensitive and reliable measure of workload (Hart and Staveland, 1988, Hill et al., 1992; Rubio, Diaz, Martin and Puente, 2004; Sherehiy and Karwowski, 2006).

- c. *Workload Profile (WTP)*. Tsang and Velazquez (1996), basing their research on the multiple resource model developed by Wickens (1984), have put forward a technique designed to combine the advantages of dual task performance procedures (good diagnostic potential) and those of subjective procedures (widely accepted, few implementation requirements and non-intrusive). Workload Profile is applied in a single stage subsequent to having performed the tasks. It uses a table which has the same number of rows as tasks performed and combinations of the same, and eight columns (one for each of the resources established in Wickens' model). These attentional resources are: Perceptive/central processing, response processing, verbal code, spatial code, visual input mode, auditory input mode, manual response mode and oral response mode. Subjects rate the proportion of attentional resources of each type used in performing the task(s) (assigning a score of either 0 or 1). Following this

the overall effort score is calculated as the arithmetical mean of the scores given for each dimension.

Procedure

All the data was gathered in the Work Psychology Laboratory of the Psychology Faculty at the Complutense University of Madrid, with the same procedure being applied to all subjects. First, the IGF test was applied to the subjects taking part in the study. In a different day, subjects performed the single and dual tracking tasks. The presentation order of the tasks was counterbalanced across the participants following a latin squares design.

The computer program registered subjects' performance. The subjective mental workload was assessed using the pencil and paper version of each instrument. Following the application procedure corresponding to each instrument, subjects using SWAT and NASA-TLX performed the first stage (scale development) of both instruments before starting the experimental tasks. The mental workload assessment of each experimental task was registered immediately following completion of each task. The total duration of the experimental session, including the instructions, the completion of the tasks and the mental workload estimates, was approximately 20-25 minutes. Due to the short extent of the tasks the potential fatigue or training effects are mitigated.

Results

First, the mental workload rate of each of the four task versions was calculated using the specific method corresponding to each instrument. All the calculations and data analyses were performed using SPSS 15.0 for Windows.

Table 1 shows the descriptive statistics (mean, standard deviation, minimum and maximum) of performance and subjective mental workload for each task combination. These results reveal that, in general, subjects' performance deteriorated and subjective mental workload increased as the complexity of the task increased.

Table 1. Descriptive statistics (mean, standard deviation, minimum and maximum) of performance and subjective mental workload for each combination.

| | Performance | | | | Mental Workload | | | |
|---------------|-------------|-------|-------|--------|-----------------|-------|------|--------|
| | Mean | SD | Min. | Max. | Mean | SD | Min. | Max. |
| Single-wide | 98.03 | 2.93 | 85.78 | 100.00 | 38.94 | 21.96 | 2.00 | 88.89 |
| Single-narrow | 87.18 | 8.83 | 43.15 | 99.50 | 52.20 | 24.01 | 8.17 | 94.44 |
| Dual-wide | 92.15 | 9.68 | 55.24 | 100.00 | 60.05 | 21.78 | 4.67 | 97.22 |
| Dual-narrow | 72.21 | 15.17 | 31.29 | 99.12 | 69.08 | 21.02 | 7.67 | 100.00 |

Table 2. Results of ANOVA applied to performance and mental workload measurements

| | Performance | | | Mental Workload | | |
|-----------------------------|-------------|------|--------------------------|-----------------|------|--------------------------|
| | $F(1,105)$ | p | Partial Eta ² | $F(1,105)$ | p | Partial Eta ² |
| Path width | 322.13 | .000 | .754 | 180.60 | .000 | .632 |
| Task condition | 163.22 | .000 | .609 | 163.96 | .000 | .610 |
| Path width * Task condition | 44.08 | .000 | .296 | 11.71 | .000 | .100 |

Effects of task complexity on performance and subjective mental workload

In order to analyse the effect of both task complexity variables repeated measures ANOVAs were applied to the performance and mental workload data using the path width and the task condition (single or dual) as within-subjects factors. Table 2 shows the results of these analyses. All effects, both simple and interaction, were statistically significant both with regard to performance and subjective mental

workload. Figure 1 shows a graph plotting the direction of these effects. Subjects obtained low performance scores and reported higher mental workload assessment under more complex conditions. All multiple comparisons between the groups formed by the interaction between the two factors of task complexity were statistically significant both with regard to performance and subjective mental workload. ($p < .001$ in all cases).

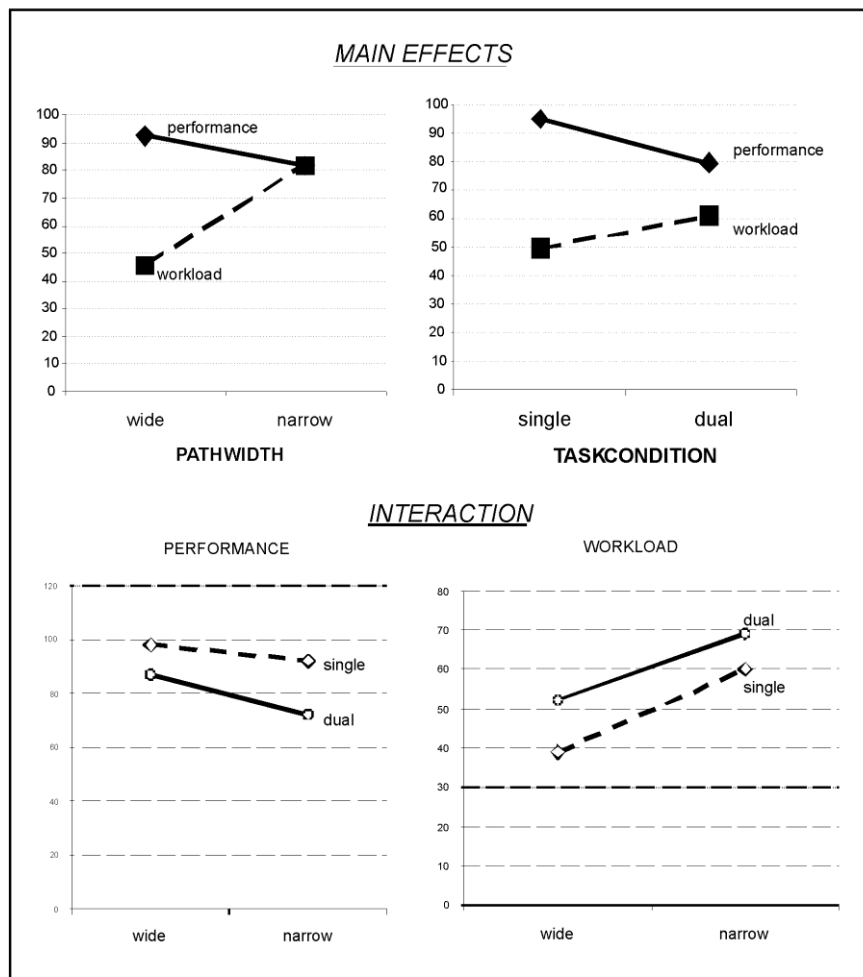


Figure 1. Main and interaction effects of path width and task condition on performance and workload.

Aptitude effects

Stepwise linear regression analysis was used to measure the possible mediating effect of intelligence variables. Linear regressions over the total average performance and the total average workload (across all tasks) revealed that spatial ability was the only good covariate for workload scores ($F(1,105) = 4.15$, $p < .05$, adjusted $R^2 = .03$). No statistically significant results emerged from any other cognitive variable

on mental workload nor any cognitive variable on performance ($p > .05$ in all cases).

Repeated measures ANOVA's were computed to analyse the possible interaction effects of task complexity factors and each aptitude variable, using the path width and task condition as within-subjects factors and each IGF variable as a covariate. The covariate represents a potential source of variance that has not been experimentally controlled but could covary with the dependent variable. The analysis of covariance permits to maintain the continuous

nature of the intelligence scores. To avoid problems due to multicollinearity between different intelligence variables, one ANOVA for each IGF variable was used. Table 3 (a and b) shows the results of these analyses with regard to performance and mental workload. With regard to measuring performance, interactions of path width and general intelligence, verbal intelligence, non-verbal intelligence, abstract reasoning and spatial aptitude were statistically significant.

In the case of mental workload, only the interaction of path width and non-verbal intelligence and path width and spatial aptitude were statistically significant. As shown in table 3b, only the effect of spatial aptitude on mental load assessments was statistically significant.

Table 4 shows the results of the multiple comparisons for the significant interactions.

Table 3a. Interaction effects of path width, task condition and cognitive abilities on performance and mental workload. (Within-subjects) (* $p < .05$ ** $p < .01$)

| INTERACTION | | Performance | | | Mental Workload | | |
|--------------------------|-------------|------------------|----------|------------------|------------------|----------|------------------|
| | | <i>F</i> (1,104) | <i>p</i> | Partial η^2 | <i>F</i> (1,104) | <i>p</i> | Partial η^2 |
| General intelligence* | Path width | 8.678 | .004** | .077 | 2.690 | .104 | .025 |
| | Condition | 2.728 | .102 | .026 | 1.150 | .700 | .001 |
| | Width*Cond. | .982 | .324 | .009 | .094 | .760 | .001 |
| Non-verbal Intelligence* | Path Width | 9.172 | .003** | .081 | 5.432 | .022* | .050 |
| | Condition | 2.324 | .130 | .022 | .343 | .559 | .003 |
| | Width*Cond. | .438 | .509 | .004 | .002 | .962 | .000 |
| Verbal intelligence* | Path Width | 4.100 | .045* | .038 | .284 | .595 | .003 |
| | Condition | 1.737 | .190 | .016 | 1.566 | .214 | .015 |
| | Width*Cond. | 1.091 | .299 | .010 | .230 | .633 | .002 |
| Abstract reasoning* | Path Width | 7.087 | .009** | .064 | 1.149 | .286 | .011 |
| | Condition | 1.249 | .266 | .012 | .765 | .384 | .007 |
| | Width*Cond. | .346 | .558 | .003 | .171 | .680 | .002 |
| Spatial aptitude* | Path Width | 4.509 | .036* | .042 | 7.898 | .006* | .071 |
| | Condition | 1.732 | .191 | .016 | .003 | .953 | .000 |
| | Width*Cond. | .214 | .645 | .002 | .130 | .719 | .001 |
| Verbal reasoning* | Path Width | 3.889 | .051 | .036 | .005 | .943 | .000 |
| | Condition | 1.228 | .270 | .012 | 1.767 | .187 | .017 |
| | Width*Cond. | .532 | .467 | .005 | .013 | .909 | .000 |
| Numerical skill* | Path Width | 2.064 | .154 | .019 | .448 | .505 | .004 |
| | Condition | 1.340 | .250 | .013 | .757 | .386 | .007 |
| | Width*Cond. | 1.172 | .282 | .011 | .436 | .510 | .004 |

Table 3b. Between-subjects. Effects of Cognitive Abilities on Performance and Mental Workload. (* $p < .05$)

| | Performance | | | Mental Workload | | |
|-------------------------|------------------|----------|------------------|------------------|----------|------------------|
| | <i>F</i> (1,104) | <i>p</i> | Partial η^2 | <i>F</i> (1,104) | <i>p</i> | Partial η^2 |
| General intelligence | 2.273 | .135 | .021 | 1.380 | .243 | .013 |
| Non-verbal intelligence | 2.493 | .117 | .023 | 2.161 | .145 | .020 |
| Verbal intelligence | 1.044 | .309 | .010 | 0.319 | .573 | .003 |
| Abstract reasoning | 3.022 | .085 | .028 | 0.230 | .633 | .002 |
| Spatial aptitude | 0.527 | .470 | .005 | 4.153 | .044* | .038 |
| Verbal reasoning | 1.086 | .300 | .010 | 1.249 | .266 | .012 |
| Numerical skill | 0.506 | .478 | .005 | 0.005 | .945 | .000 |

Table 4. Results of multiple comparisons on performance and mental workload

| PERFORMANCE | Single wide vs. Single narrow | | | Dual wide vs. Dual narrow | | | Single wide vs. Dual narrow | | | Single narrow vs. Dual wide | | |
|-------------------------|-------------------------------|----------|------------------|---------------------------|----------|------------------|-----------------------------|----------|------------------|-----------------------------|----------|------------------|
| | <i>F</i> | <i>p</i> | Partial η^2 | <i>F</i> | <i>p</i> | Partial η^2 | <i>F</i> | <i>p</i> | Partial η^2 | <i>F</i> | <i>p</i> | Partial η^2 |
| | (1,105) | | | (1,105) | | | (1,105) | | | (1,105) | | |
| General Intelligence | 5.16 | .025 | .047 | 5.69 | .019 | .052 | 7.86 | .006 | .070 | 0.82 | .368 | .008 |
| Verbal Intelligence | 1.60 | .209 | .015 | 3.37 | .069 | .031 | 3.78 | .055 | .035 | 0.58 | .447 | .006 |
| Non-verbal intelligence | 7.10 | .009 | .064 | 5.09 | .026 | .047 | 8.22 | .005 | .073 | 1.23 | .270 | .012 |
| Spatial Aptitude | 3.56 | .062 | .033 | 2.53 | .115 | .024 | 0.41 | .522 | .004 | 0.74 | .391 | .007 |
| Abstract Reasoning | 5.50 | .021 | .050 | 3.97 | .049 | .037 | 5.92 | .017 | .054 | 2.48 | .118 | .023 |
| WORKLOAD | | | | | | | | | | | | |
| Non-verbal intelligence | 3.82 | .053 | .035 | 3.09 | .082 | .029 | 2.78 | .098 | .026 | 0.35 | .556 | .003 |
| Spatial Aptitude | 4.29 | .041 | .040 | 5.61 | .020 | .051 | 1.99 | .161 | .019 | 1.59 | .210 | .015 |

Following Gonzalez (2005) participants were classified according to their mean IGF scores as low or high individuals. This classification was done only for the purposes of illustrating the IGF scores x path width interactions and the main effect of the spatial ability score on performance and

workload (see figure2). No analyses were conducted with a split sample; rather, statistics were calculated on the whole sample, using the continuous variables of the IGF test scores.

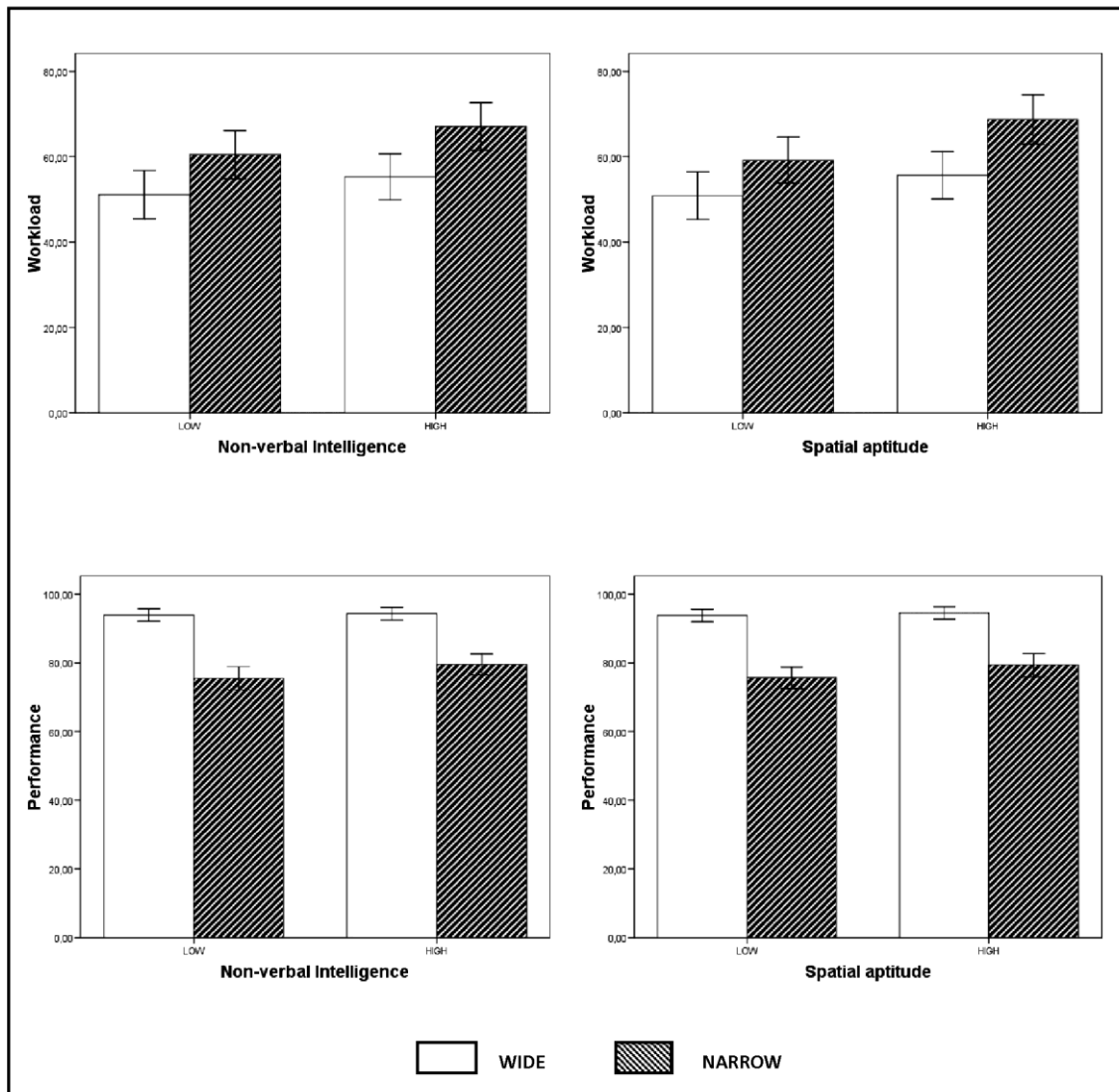


Figure 2. Means of workload and performance for subjects with high versus low ability levels.

Figure 2 shows the interactions which were especially significant from the above analysis, both with regards to performance and mental workload. With regard to performance it can be seen that this is lower when the path is narrow and that the subjects with higher ability show a higher time-correctly-tracking percentage that those with less ability, particularly in the more difficult situation (narrow path). With respect to mental workload, it can be seen that the tracking task obtains significantly lower mental workload assessments when the path is wide and that, against expectations, the subjects with greater ability report significantly higher mental

workload assessments than those less able. This is true for both tracking task difficulty levels, and especially when the path is narrow.

Figure 3 (a and b) plots the relation between spatial aptitude and performance and mental workload across the four different tasks. A similar pattern was found for the others cognitive abilities that were significant. Figure 3 shows how performance and mental workload increased as ability score was greater, especially in the most complex condition (dual-narrow).

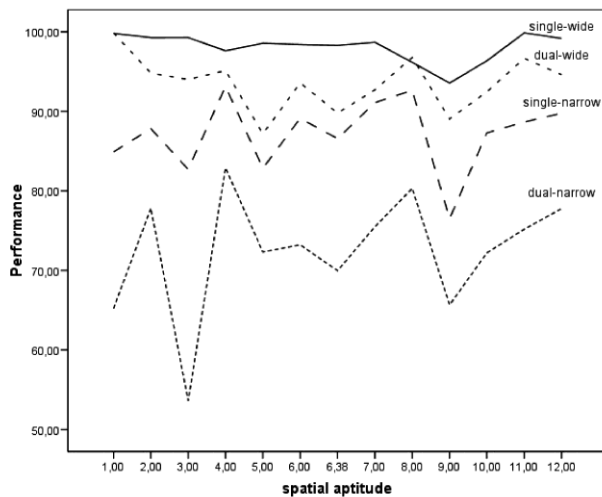


Figure 3a: Plot of performance vs. spatial aptitude for each tracking task.

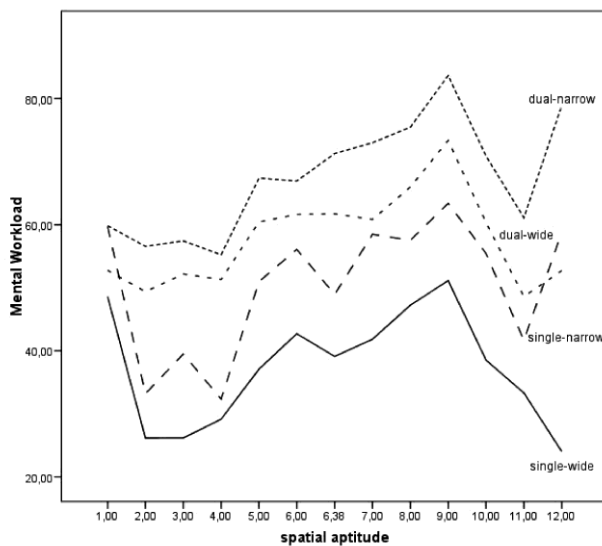


Figure 3b. Plot of mental workload vs. spatial aptitude for each tracking task.

To analyse whether or not these differences in assessing mental workload recorded between ability groups could be attributed to the instrument used, we applied an ANOVA, using as between-subjects factors the spatial aptitude group (high-low ability) and the instrument (SWAT, NASA-TLX, WP) on the z-scores of mental workload assessments reported for each of the four tracking tasks used. The aim of this analysis was to assess the interaction effect between both between-subjects factors. This interaction effect was not significant in any of the cases ($F(1,100)=0.054$, $p=.947$ for the mental workload of the single-wide task; $F(1,100)=0.010$, $p=.990$ for the mental workload of the single-narrow task; $F(1,100)=1.210$, $p=.303$ for the mental workload of the dual-wide task; $F(1,100)=0.473$, $p=.625$ for the mental workload of the dual-narrow task). We concluded

that the fact that subjects with greater ability report higher mental workload assessments is not related to the instrument used, as the most intelligent subjects reported significantly higher workloads than those of less ability in all four tasks using all three measuring instruments.

Finally, an ANOVA was performed to compare the subjects' performance in the secondary memory task. No statistically significant differences were found between the mean time of correct hits in the memory task ($F(1,102)=0.102$, $p=0.750$, $\eta^2=0.001$).

Conclusions

The main aim of this study was to analyse the possible mediating effect of the aptitude level of individuals on performance and subjective mental workload involving a tracking task of varying complexity. The individual aptitudes considered were: spatial aptitude, abstract reasoning, verbal reasoning and numerical skill. The complexity of the tracking task varied according to the path width and whether or not a simultaneous memory task was also included. As we expected, the results showed that as the tracking task became more complex performance declined and perception of mental workload increased, as statistically significant effects relating to path width, single or dual task condition, and the interaction of both factors, were found both with regard to performance and assessment of mental workload. The effect sizes revealed that a great part of the variance of performance and subjective mental workload is due to task complexity factors.

In addition to this, taking into account the aptitude level of the individuals, we found that firstly, when the average scores of performance and mental workload across all tasks were considered, only the effect of spatial ability on workload was significant. No significant results emerged from any cognitive variable on performance. These results are consistent with Bunce and Sisa (2002) and Deaton and Parasuraman (1993) findings.

As was expected taking into account the characteristics of the tracking task (visual, manual and spatial), numerical skill and verbal reasoning had no effect on performance or mental workload, either simply or in interaction with task complexity factors. With regard to abstract reasoning ability, the effects of this aptitude were shown only on performance and in interaction with path width.

The subjects' spatial aptitude had the greatest moderating effect on mental workload. In this respect, the interaction effect between spatial aptitude and path width on mental workload was found. The simple effect of spatial aptitude on subjective workload assessment was also significant. Although the effect sizes of the significant interactions were small, we consider that taking account that the greater percent of the variance of performance and mental workload was due to task complexity factors, effect sizes from 3.8% to 8.1% are acceptable.

With regard to performance it can be seen that this was lower when the path was narrow and that the subjects with higher ability show a higher time-correctly-tracking percentage than those with less ability, particularly in the more difficult situation (narrow path). This result confirms that obtained in previous research on the effects of task difficulty and individual's cognitive ability on standards of performance (Gonzalez, 2005). The cognitive variables that showed a greater moderating effect on performance in interaction with path width were general intelligence, non-verbal intelligence and abstract reasoning.

With respect to the mental workload, the tracking task obtained significantly lower mental workload assessments with the wide path and, against our expectations, subjects with greater ability reported significantly higher mental workload assessments than those less able. This was true for all tracking task difficulty levels and irrespective of the instrument used to measure the subjective mental workload. This unexpected result, which contradicts our expectations based on mental workload models (i.e., the greater the individual ability, the greater the performance with less mental workload) and in the negative relation between performance and mental workload found in other studies (Warm et al., 2008), if confirmed in subsequent research, could have important implications for the analysis of subjective mental workload for different types of task. First, it would be necessary to redefine the concept of mental workload in general and, more specifically, that of subjective mental workload. We would also recommend that mental workload models include new variables, mainly related to individual differences, which could influence workers' perceptions of mental workload. Finally, echoing the results obtained by Xie and Salvendy (2000), it is evident that if mental workload is not solely determined by task variables but also by individual factors, most future research efforts within this field should be aimed at determining which individual variables are important and what influence they exert. This is the only means of knowing and predicting mental workload levels (perceived by workers) associated with a particular task and not only the task load (which by definition is objective). As the stress-strain relation is mediated by individual factors (ISO 10075), only by taking individual ability into account can company directors distribute workloads correctly among

their workers in order to avoid the emergence of frustration, anxiety, stress and their detrimental effects on workers' health (Genaidy, Salem, Karwowski, Paez and Tuncel, 2007). Therefore, to ensure optimal matching of job and worker, and to achieve adequate levels of safety and performance, the effect of individual differences, together with the demands of the job and the characteristics of the task, must be considered (Szalma, 2008).

The results of this study open new ways for future research. First, it must be confirmed that individuals with greater ability have a higher assessment of mental workload by carrying out additional studies in which the aptitude profile of the subjects, the subjective mental workload and performance achieved when performing different task are measured using larger sample groups. Secondly, we would recommend further analysis be carried out to assess why subjects with greater ability perceive more mental workload. As ISO 10075 recognizes it is possible that the effect of cognitive abilities on mental workload assessments are mediated by other individual differences variables as personality, motivation, attitudes, etc. This result could be due to motivational and self-demanding factors where more intelligent subjects are more willing to achieve higher levels of performance, which prompts them to make greater efforts than those with less ability.

Another hypothesis, one which complements the above, could involve the concept of self perceived efficiency, where more intelligent individuals feel more frustrated and dissatisfied when they fail to carry out a task than those with less ability; this would lead them to perceive high levels of mental workload. In both cases, the explanation will be related to the goals each individual sets for himself or herself when confronted with the need to carry out any activity, and different mental effort regulation mechanisms (Young and Stanton, 2001; Fairclough, 2001). Finally, other factors such as a subject's personality, attitude, habits, emotional state or experience, can have a significant impact on the level of perceived mental workload resulting from carrying out a particular task (Szalma, 2008). As ISO 10075 recommended this should also be analysed in future research.

Acknowledgments.- This research was supported by Universidad Complutense de Madrid (Reference number: PR78/02-11036)

References

- Ackerman, P.L. (1988). Determinants of individual differences during skills acquisition: Cognitive abilities and information processing. *Journal of Experimental Psychology: General*, 117, 288-318.
- Ben-Shakhar, G., and Sheffer, L. (2001). The relationship between the ability to divided attention and standard measures of general cognitive abilities. *Intelligence*, 29, 293-306.
- Boles, D.B., Bursk, J.H., Phillips, J.B. and Perdelwitz, J.R. (2007). Predicting dual-task performance with the multiple resources questionnaire (MRQ). *Human Factors*, 49, 1, 32-45.
- Bunce, D. and Sisa, L. (2002). Age differences in perceived workload across a short vigil. *Ergonomics*, 45, 13, 949-960.
- Crutchfield, J. and Rosenberg, C. (2007). *Predicting Subjective Workload Ratings: A Comparison and Synthesis of Operational and Theoretical Models*. (DOT/FAA/AM-07/6). Washington, DC:FAA Office of Aerospace Medicine.
- Deaton, J.E. and Parasuraman, R. (1993). Sensory and cognitive vigilance: effects of age on performance and subjective workload. *Human Performance*, 6, 1, 71-97.
- Fairclough, S.H. (2001). Mental effort regulation and functional impairment of the driver. In P.A. Hancock and P.A. Desmond (Ed.), *Stress, Workload and Fatigue*. New Jersey: Lawrence Erlbaum Associates, Publishers (pp. 479-502).

- Genaidy, A.; Salem, S.; Karwowski, W.; Paez, O. and Tuncel, S. (2007). The work compatibility improvement framework: an integrated perspective of the human-at-work system. *Ergonomics*, 50, 1, 3-25.
- Gonzalez, C. (2005). Task workload and cognitive abilities in dynamic decision making. *Human Factors*, 47, 1, 92-101.
- Gopher, D. and Donchin, E. (1986). Workload: An Examination of the Concept. In K. Boff, L. Kaufman and J.P. Thomas (Eds.), *Handbook of Perception and Human Performance*. New York: Wiley & Sons.
- Hancock, P.A. and Meshkati, N. (Eds.) (1988). *Human Mental Workload*. Amsterdam: Elsevier.
- Hancock, P.A., Williams, G., Miyake, S. and Manning, C.M. (1995). The influence of task demand characteristics on workload and performance. *International Journal of Aviation Psychology*, 5, 63-85.
- Hart, S.G. and Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In P.A. Hancock and N. Meshkati (Eds.), *Human Mental Workload*. Amsterdam: North-Holland.
- Hill, S.G., Iavecchia, H.P., Byers, J.C., Bittner, A.C., Zaklad, A.L. and Christ, R.E. (1992). Comparison of four subjective workload rating scales. *Human Factors*, 34, 429-439.
- ISO 10075 (1991). *Ergonomic Principles Related to Mental Work-load: Part I: General Terms and Definitions*.
- Johnson, A., and Proctor, R.W. (2004). *Attention. Theory and Practice*. London: Sage.
- Legree, P.J., Heffner, T. S., Psotka, J., Martin, D. E. and Medsker, G. J. (2003). Traffic crash involvement: experiential driving knowledge and stressful contextual antecedents. *Journal of applied psychology* 58, 1, 15-26.
- Meshkati, N. (1988). Toward development of a cohesive model of workload. In P.A. Hancock and N. Meshkati (Eds.), *Human mental workload*. Amsterdam: North Holland.
- Miyake, S., Loslever, P. and Hancock, P.A. (2001). Individual differences in tracking. *Ergonomics*, 44, 12, 1056-1068.
- Morris, C.H. and Leung, Y.K. (2006). Pilot mental workload: how well do pilots really perform?. *Ergonomics*, 49, 15, 1581-1596.
- O'Donell, R. and Eggemeier, F. T. (1986). Workload assessment methodology. In K. R. Boff, L. Kaufman and J. P. Thomas (Eds.), *Handbook of perception and human performance*, 42, 1-49. New York: Wiley.
- Pretorius, A. and Cilliers, P.J. (2007). Development of a mental workload index: A systems approach. *Ergonomics*, 50, 9, 1503-1515.
- Recarte, M.A., Perez, E., Conchillo, A. and Nunes, L.M. (2008). Mental workload and visual impairment: Differences between pupil, blink and subjective ratings. *The Spanish Journal of Psychology*, 11, 2, 374-385.
- Reid, G.B., Eggemeier, F.T. and Singledecker, C.A. (1982). Subjective workload assessment technique. *Proceedings of the 1982 ALAA Workshop on Flight Testing to Identify Pilot Workload and Pilot Dynamics*, 281-288.
- Reid, G.B., Singledecker, C.A. and Eggemeier, F.T. (1981). Application of conjoint measurement to workload scale development. *Proceedings of the Human Factors Society Annual Meeting*, 522-526.
- Rubio, S. (1992). *Evaluación y Medida de la Carga Mental en una Tarea de Diagnóstico de Fallos*. Madrid: Universidad Complutense de Madrid.
- Rubio, S. (1993). Efectos de la complejidad de una tarea de detección de fallos sobre la carga subjetiva. *Revista de Psicología del Trabajo y de las Organizaciones*, 9, 25, 145-164.
- Rubio, S., Díaz, E. M., Martín, J. and Puente, J.M. (2004). Evaluation of subjective mental workload: a comparison of SWAT, NASA-TLX and Workload Profile methods. *Applied Psychology: An International Review*, 53, 61-86.
- Sherehiy, B. and Karwowski, W. (2006). Subjective scales of effort and workload assessment. In W. S. Marras and W. Karwowski (Eds.), *Fundamental and Assessment Tools for Occupational Ergonomics*. London: Taylor & Francis.
- Szalma, J.L. (2008). Individual differences in stress reaction. In P.A. Hancock and J.L. Szalma (Eds.), *Performance Under Stress*. Hampshire: Ashgate.
- Taylor, J. L., O'Hara, R., Mumenthaler, M. S., Rosen, A. C., and Yesavage, J. A. (2005). Cognitive ability, expertise, and age differences in following air-traffic control instructions. *Psychology and Aging*, 20, 1, 117-133.
- Tsang, P.S. and Velazquez V.L. (1996). Diagnosticity and multidimensional subjective workload ratings. *Ergonomics*, 39, 3, 358-381.
- Tuholski, S.W., Engle, R.W., and Baylis, G. C. (2001). Individual differences in working memory capacity and enumeration. *Memory and Cognition*, 29, 484-492.
- Vitense, H.S., Jacko, J.A. and Emery, V.K. (2003). Multimodal feedback: an assessment of performance and mental workload. *Ergonomics*, 46, 1-3, 68-87.
- Warm, J. S., Matthews, G., and Finomore, V.S. (2008). Vigilance, workload, and stress. In P.A. Hancock and J.L. Szalma (Eds.), *Performance under Stress*. Hampshire: Ashgate.
- Welford, A. T. (1986). Mental Workload as a function of demand, capacity, strategy and skill. *Ergonomics*, 21, 151-176.
- Wickens, Ch. D. (1984). *Engineering Psychology and Human Performance*. Columbus, OH: Charles Merrill.
- Wickens, Ch. D. (2008). Multiple resources and mental workload. *Human Factors*, 50, 3, 449-455.
- Xie, B. and Salvendy, G. (2000). Review and reappraisal of modelling and predicting mental workload in single- and multitask environments. *Work and Stress*, 14, 1, 74-99.
- Young, M. S. and Stanton, N.A. (2001). Mental workload: theory, measurement, and application. In W. Karwowski (Ed.), *International Encyclopedia of Ergonomics and Human Factors: Volume I*. London: Taylor & Francis. (p. 507-509).
- Young, M. S. and Stanton, N.A. (2002). It's all relative: defining mental workload in the light of Annett's paper. *Ergonomics*, 45, 14, 1018-1020.
- Yuste, C. (1997). *IGF. Inteligencia General y Factorial*. Madrid: Tea Ediciones.

(Article received: 08-04-2010, reviewed: 19-10-2011, accepted: 12-11-2011)