Abstract  Technological advances, modified work practices, altered employment strategies, work-related injuries, and the rise in work-related litigation and compensation claims necessitate ongoing trade analysis research. Such research enables the identification and development of gender- and age-neutral skills, physiological attributes and employment standards required to satisfactorily perform critical trade tasks. This paper overviews a methodological approach which may be adopted when seeking to establish trade-specific physiological competencies for physically-demanding trades (occupations).

A general template is presented for conducting a trade analyses within physically-demanding trades, such as those encountered within military or emergency service occupations. Two streams of analysis are recommended: the trade analysis and the task analysis. The former involves a progressive dissection of activities and skills into a series of specific tasks (elements), and results in a broad approximation of the types of trade duties, and the links between trade tasks. The latter, will lead to the determination of how a task is performed within a trade, and the physiological attributes required to satisfactorily perform that task. The approach described within this paper is designed to provide research outcomes which have high content, criterion-related and construct validities. J Physiol Anthropol 22 (2): 73–81, 2003 http://www.jstage.jst.go.jp/en/

Keywords: employment standards, ergonomics, physical demands, physiological competencies, trade task analysis

Introduction

A wide range of factors within the workplace necessitate ongoing trade analysis research. These include: technological advances, modified work practices, changes in employment strategies, identification and recognition of work-related injuries (acute and chronic), altered population health standards, and the continued rise in both work-related litigation and compensation claims. For these reasons, it is incumbent upon the employer, as part of the duty of care obligation, to fully understand the physical demands of the key duties (tasks) within each relevant trade, and to take the necessary steps to minimise the hazards associated with the physiological impact of these tasks upon the employee. In this paper, we shall focus specifically upon trades (occupations) in which there is a high proportion of physically-demanding tasks.

Trade-analysis research enables the identification and development of gender- and age-neutral skills, physiological attributes (competencies) and (physical) employment standards required to satisfactorily perform the critical tasks within a given trade. This paper focusses primarily upon a methodological approach leading to the establishment of trade-specific physiological competencies.

Physiological Competency

Physiological competencies are derived by integrating knowledge obtained from trade and task analyses. This information is combined with data derived from the physiological analysis of personnel who demonstrate task performance at, or above, the trade-specific performance threshold (criterion performance) to provide a projected physiological profile of individuals who can effectively perform the key physically-demanding trade tasks, with minimal risk of injury. Herein, we shall concentrate specifically upon the physical and physiological analysis methods which are suited to the more physically-demanding trades, such as those found within the military and emergency service trades.

Physical Employment Standards

From the range of physiological competencies derived for any given trade, it becomes possible to categorise each competency according to its importance, relative to the overall trade performance, and thereby provide the basis upon which a prescription may be made for screening and barrier test
development. To these screening tests may be applied achievement goals, or standards, which represent the physiological and physical attributes necessary for any individual to achieve the desired performance, while, at the same time, minimising the risk of work-related injury.

These employment standards provide a foundation upon which human resource management may be built, and from which the development of screening tests may occur. Such tests may be used as a means by which new and existing personnel may be recruited, trained, retrained, developed and appraised. Furthermore, trade-analysis research can lead to significant modification and redesign of the more stressful duties. Indeed, one may consider trade analysis research to be the first of several steps designed to bring about a more productive, and less stressful, integration of the worker within the workplace, and the working environment.

The careful and well-structured implementation of the outcomes derived from thorough, science-based analyses, can result in a wide range of work-related outcomes, including: (1) more effective personnel recruitment: with superior maintenance of relevant physical attributes, and reductions in the time required for physical training; (2) reduced stress- and strain-related injury: with fewer hours lost to such injuries; and (3) increased individual and group capability and productivity.

Apart from the obvious benefits to human resource management, these outcomes are also associated with significant fiscal benefits. For instance, the U.S. Navy determined that, between 1989-91, about $1.2 million was unnecessarily spent on personnel training, at a single training centre, because recruits did not meet the appropriate physical requirements for that trade (Marcinik et al., 1995). The Vancouver Fire Department estimated an annual saving of $23,000, when it modified its recruit selection procedures to better match the skills and employment standards of firefighting (Brownlie et al., 1985).

In this paper, we provide a generalised template around which one may develop a work-based, physical and physiological assessment of physically-demanding trades. Based upon the assumption that individuals are required to achieve pre-determined performance standards within a local environment and organisational structure, both of which interact with personal skills and attributes, it is recommended that a systems-analysis research model be adopted for such trade analyses (Shepherd, 2001; Wolfe et al., 1991). This approach has the potential to provide a more complete understanding of the trade tasks, and a better appreciation of the individual tasks, within the context of the overall working environment, and forms the basis of this recommended model. Within this systems-analysis model, it is useful to also apply the demand-capacity analysis approach, wherein one quantifies the absolute physical demands of the trade, and then relates these to the capacity of the worker to complete each task. When this demand-capacity analysis is performed with respect to normative data for the target population, one may be able to predict the number of people, from each gender, capable of satisfying these physical demands.

The Generic Planning Model

An overall, generic planning model for conducting trade analysis research is summarised in Figure 1. The model has implicit hierarchical (top-to-bottom) and chronological implications (left-to-right). For the purposes of this paper, we shall focus only upon the two leftmost components: the trade and task analyses.

Step one: Trade analyses

Trade analyses involve the progressive dissection of activities and skills (general tasks), normally performed as part of the trade duties, into a series of levels of specific tasks.
(elements), with each level increasing in task specificity. This analysis allows a broad approximation of the types of duties integral to successful performance within a trade, and leads to the establishment of links between task elements. In addition, these analyses will result in a description of the working environment in relation to the tasks performed, the materials handled, the task performance expectations, and the workplace.

1) Establish trade priorities

The first step in this stream of the planning model (Figure 1) is to develop a clear understanding of the global and local priorities of the trade. This requires, within reasonable limitations, the researcher to learn about the physical domains which exist within the trade tasks, and which may reasonably be expected to be performed by personnel within the trade, as well as the overall operational roles, responsibilities and missions that may impact upon these tasks. It is our experience that meaningful, thorough, co-operative, and therefore successful trade analyses can only eventuate if time has first been dedicated to developing an understanding of each trade. Without this step, the researchers cannot see the “whole picture”, they cannot understand the relative importance of individual tasks, and are they unable to appreciate where, and how, each trade task fits within the overall role of the operational unit.

To illustrate this process, we shall use here, and below, the example of a trade task analysis recently performed on Royal Australian Navy (RAN) Clearance Divers (Taylor et al., 2000). Trade prioritisation led to the identification of 18 physically-demanding tasks, which were grouped into three general categories:

1) Land-based materials handling: Truck loading and unloading, Zodiac (inflatable boat) handling, outboard motor handling, mine lifting bag handling, “jackstay” handling (weights to secure line to seabed), compressor handling, loaded diver walking (“stomping”), chain block handling, welding equipment handling, bomb suit handling.

2) Water-based materials handling: Mine lifting bag handling, “jackstay” handling, unconscious diver handling, underwater materials handling.

3) Operational insertion: Inshore boat exit and entry, ship (ladder) water exit and entry, endurance swim, fast roping.

2) Develop an analysis plan

The next step in the model involves developing a plan for identifying the key trade tasks to be analysed, and how the researchers may optimise their productivity, whilst minimising the disruption of operational duties. At this step, the researchers will also meet the major stakeholders. They will invariably come to this meeting having only a generalised understanding of the roles of the trade, and the unit with which it is associated. This meeting will be used to further develop that understanding, and also to seek trade- and unit-specific information to define the operational parameters for the project, and to identify individual, unit or organisational factors which may impact upon performance of the individual.

3) Identify resources

Within any trade, there exists various levels and forms of resource information which represent an essential background, upon which the task analyses may be based. In many instances, written procedures, training manuals and incident reports will be available. However, these should be supplemented using the collective memory of the workers, particularly those with most experience.

4) Identify validation methods

The final step in this stream requires the development of strategies and methods through which the research team may validate the research procedures and outcomes, particularly as they may relate to the development of employment standards. This step is an extremely important part of this whole process, as it influences the acceptance and implementation of the research recommendations, and can even have legal ramifications concerning the equality of employment opportunities. In this regard, readers are advised to familiarise themselves with the Equal Employment Opportunity regulations which may pertain to their country, as they relate to the implementation of screening tests and physical employment standards. Generally, the satisfaction of such regulations requires that screening procedures are directly related to the duties and responsibilities of the trade, that the physically-demanding attributes of the trade have been accurately and thoroughly established, that the employment standards are reasonable reflections of the trade across all relevant working environments, and that standards reflect the current physical and physiological attributes, and not those which may be predicted to exist in the future.

The validation process of the trade analysis method forms an integral part of the equal opportunity requirement. However, since this process can often have very different connotations among the scientific disciplines, the validation methods should be established prior to commencing the project. To the experimental scientist, validation means the establishment of methods by which one can verify that each measurement procedure actually measures the characteristic or attribute that was intended to be measured, with minimal reactive error (artefact induced by taking the measurement). This definition of validity is critical to all data collection methods. To some ergonomists, validity may mean that one ensures that the methods used are well-substantiated and useful (Athansou et al., 1993). To many managers, the validity requirement can simply imply that one must employ a trained scientist to undertake the task assessments; it is valid because it was undertaken by an expert.

In the context of the current paper, we address validity as it relates to measurement procedures used during the task analysis, and also to any screening tests, or employment standards, derived from such analyses. These are inextricably linked, so both aspects will be covered simultaneously. Indeed,
one can generally conclude that the most valid trade assessment is undertaken while someone performs the trade tasks themselves. Since this is not possible for most screening test applications, one must give serious consideration to three forms of validity (American Psychological Association, 1987).

The first form of validity relevant to trade task analyses is logical validity, which is a specific form of content validity, and particularly relevant to skilled tasks. For task analysis procedures, and the resulting screening tests, to be logically valid, both must cover the principal components of the skills and tasks necessary to perform the trade. That is, all of the most important (physically-demanding) elements of the job must be analysed, such that a resultant screening test truly reflects the trade, and is inherently linked to that trade. These skills and tasks make up the physical and physiological domains which may be used to describe the trade.

Logical validity can be readily established through the use of a within-trade, expert working party, which provides the scientist with the necessary background information to undertake the trade analysis. The composition of this group is critical, as it must have representation from both workers and managers, and must be accepted by both parties as an unbiased expert panel. This group, perhaps supplemented by a National or International review panel, should work continuously with the research team to ensure that procedural validations and peer reviews lead to the implementation of methods which are logically valid for the trade under investigation. The methods outlined herein work directly towards this outcome.

At present, the screening test for RAN Clearance Divers lacks logical validity. This test uses five activities: a 500-m fin swim, a 2.4-km run, and push-up, sit-up and pull-up tests. Some of these test items do involve the assessment of physiological attributes which may be deemed essential to Clearance Diver operations, yet few could be considered to be job-specific (Taylor et al., 2000). It is not adequate simply to establish that some physiological attribute (e.g. strength) is important to a group of trade tasks, without also establishing how that attribute is utilised within the trade (e.g. 44% of tasks involved land-based, lift and carrying activities primarily using upper-body muscle groups). Indeed, the RAN test items, which are a simple replication of those applied within the U.S. Navy, are poorly correlated with diver performance (Marcinik et al., 1995; Beckett and Hodgdon, 1987). Accordingly, the test, while easy to administer, has a very poor content validity, and is not based upon a thorough scientific trade analysis.

The second form of validity is criterion-related validity, which is typically established through the use of correlation analyses, to compare experimental or outcome measures with an established criterion reference. This form of validity also relates to both the trade analysis procedures and to the outcomes from resultant screening tests. In the former instance, various techniques are employed to establish the required methodological (concurrent) validity, including the use of criterion techniques, scientists and laboratories. In the latter case, the predictive capacity of screening procedures may be established (predictive validity) against some form of objective or subjective trade-performance measure, or against some target outcome (e.g. reduced work-related injuries, increased productivity and capability). During this step, validation methods must be established for both concurrent and predictive validity.

Third, we must consider construct validity. This type of validity relates to attributes (constructs) which cannot easily be measured (non-quantifiable traits). For instance, we know that trade performance is a multi-faceted quality. While we can measure some aspects which are related to trade performance, we may be unable to quantify performance per se. However, for trade screening tests, one may be able to quantify construct validity by comparing screening test results with actual job behaviours. This first requires the establishment of a set of behaviours (trade tasks) required to satisfactorily perform a trade. These are identified by the expert working party, and then analysed by the research team to identify physiological attributes which underpin trade performance (e.g. strength and local muscle endurance). These attributes may then be weighted, or ranked, in order of contribution to successful trade performance. A screening test with high construct validity will measure these same attributes, and will be well correlated with independent indices of the same physiological and physical attributes.

Step two: Task analyses

The principal emphasis of this paper is the trade task analysis. These tasks are comprised of related activities involving interactions with both equipment and people. Trade tasks generally have clearly-defined start and end points, and, whilst varying in both size and complexity, are always directed towards achieving a specific outcome (goal). Through task analysis, one can to broadly determine how a task is performed within a trade, and the physiological attributes which are required to perform this task. As such, task analyses involve much more than generating lists of duties, as each trade may be comprised of many different sub-tasks, such that each task may have several primary elements and attributes. In some cases, an hierarchical task analysis approach may be appropriate (Shepherd, 1991), with this usually undertaken where there are interactions of several layers of attributes from across various physical, physiological, psychological and even social domains. In the current application, however, hierarchical analyses are not generally required, and five steps are recommended to complete this research stream.

1) Interview stakeholders

Several levels of interviews may be required, depending upon the complexity of the management structure. These interviews should follow a top-down approach, and must lead to the development, and iterative modification, of an inventory of key trade tasks. This inventory must relate only to the operationally-significant duties within the trade. Furthermore, its derivation must involve consultation between all of the
stakeholders, including the personnel who routinely perform these tasks. Indeed, it is the managers and the workers who dictate the trade tasks which are ultimately studied by the research team. It is our experience that a culture of shared ownership, and dedicated and enthusiastic involvement in the research process emanates from such a consultative approach. These interviews should target organisational factors, local environmental factors and personal attributes which dictate, and modify, satisfactory trade performance standards (Table 1).

2) Determine analysis end points
To undertake trade task analyses cost effectively and efficiently, it is very important to know when to terminate the task analyses. Termination should occur when the tasks analysed, or the physical abilities studied, are no longer critical to satisfactorily performing the operationally-significant duties of the trade, or when the tasks simply involve the repetition of attributes already assessed. For example, one may arrive at a vast, and unmanageable, array of trade tasks unless delimited by the stakeholders and researchers. While such lists may be quite useful in certain circumstances, they can make trade task analyses unnecessarily complex, with parts of the process becoming trivialised and irrelevant. Since the research team will not necessarily know the appropriate analysis termination points, these must be determined in consultation with personnel within each trade.

To illustrate this point, we have observed that RAN Clearance Divers must handle more than 1,500 items during a typical operational loadout, with a total mass in excess of 43,000 kg, and an average item mass of 28.2 kg. Twenty different items were 60 kg or more in mass, and 14 of these items were greater than, or equal to, the average mass of the divers tested (Taylor et al., 2000). While one could argue that every item, by definition, was operationally-significant, the observation of divers handling all 1,500 items would have an extremely low outcome to observation ratio. In this situation, items could be grouped, with observations being restricted to unique items from each group. Thus, in this case, the end point of the trade analysis is moved in favour of analysis simplification. In other cases, tasks which have minimal operational relevance could be entirely eliminated.

3) Identify key task elements
Within this step, movement analysis is typically performed using still and video photography, so that the relevant key muscle groups and movement elements can be identified for each task. Commonly, such analyses will include a description of the type of muscle activation (concentric, eccentric, isometric, isokinetic), joint ranges of motion, angular velocities, and muscle functions and inter-relationships (e.g. identification of prime movers, antagonists, synergists, stabilisers and neutralisers). More sophisticated techniques involving measures of muscle activation, force generation, and postural changes may be used to supplement this information.

For example, when land-based, materials-handling tasks were evaluated for RAN Clearance Divers (Taylor et al., 2000), movement analysis of divers carrying a 50-Hp outboard motor revealed that seven major muscle groups were recruited: elbow flexors, trunk stabilisers, wrist flexors, hip and knee flexors and extensors. The main movement elements were lifting, carrying and lowering the object. When such analyses were completed across the 18 tasks analysed, it was possible to develop an overall picture of the key task elements, and an understanding of how these tasks were combined within this trade (Table 2). All of the land-based, materials-handling tasks (56% of all tasks analysed) relied upon upper-body muscle recruitment, with seven of the ten involving lifting and carrying actions.

4) Identify task attributes
Task attribute evaluations represent the most complex facet of the task analysis project, for which one may undertake both subjective and objective assessments. In the former instance, one seeks to obtain knowledge relating to the importance of each task, its performance difficulty and the frequency with which it is performed. Objective evaluations focus upon physical measurements of the workplace, its environment and the equipment used, and also the physiological and biomechanical responses associated with task performance.

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**Table 1** Interviews with stakeholders: task-performance modifiers

| Organisational factors | Trade history (culture and climate) |
| Local environmental factors | Mission and goals of the trade |
| Personal attributes | Overall strategies, tactics or plans of trade |

**Table 2** Summary of land-based, materials-handling tasks: principal movement elements (modified from: Taylor et al., 2000)

<table>
<thead>
<tr>
<th>Task Action</th>
<th>Task Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Truck loading</td>
<td>lift: upper body</td>
</tr>
<tr>
<td>Zodiac handling: deflated carriage</td>
<td>lift, carry: upper body</td>
</tr>
<tr>
<td>Zodiac floor carriage</td>
<td>lift, carry: upper body</td>
</tr>
<tr>
<td>Zodiac handling: inflated carriage</td>
<td>lift, carry: upper body</td>
</tr>
<tr>
<td>Outboard motor carriage</td>
<td>lift, carry: upper body</td>
</tr>
<tr>
<td>Mine lift bag carriage</td>
<td>lift, carry: upper body</td>
</tr>
<tr>
<td>“Jackstay” handling and carriage</td>
<td>lift, carry: upper body</td>
</tr>
<tr>
<td>Compressor carriage</td>
<td>lift, carry: upper body</td>
</tr>
<tr>
<td>“Stomping”</td>
<td>carry: upper body</td>
</tr>
<tr>
<td>Bomb suit</td>
<td>carry: upper body</td>
</tr>
</tbody>
</table>
Subjective evaluation: Assessments of task importance, difficulty and performance frequency provide information which allows one to undertake a first-level prioritisation of tasks within each trade. Using data collected on RAN Clearance Divers (Taylor et al., 2000), we shall illustrate how this process may be undertaken. The Divers ranked each of the chosen tasks on a difficulty scale from 1–10 (e.g. 1 = desk work, 10 = most strenuous and physically demanding of all duties). It is important to note that considerable variation in difficulty rating should be anticipated, even within somewhat homogenous population samples. This variation possibly reflects differences among the individual physiological characteristics within a somewhat homogenous population sample, and it reinforces the need for the researchers to collect data from a wide range of workers.

Divers also reported how many times the selected tasks were performed within an average month, over a 12-month period. The key factor to consider here is that, whilst some tasks may be very difficult, they may represent minimal annual strain, if they are infrequently performed. Perhaps a more useful way in which to look at these data can be found in the simple product of the difficulty rating and the task frequency. This product has been defined as the subjective cumulative task stress index. It is driven equally by each component, it permits an assessment of cumulative stress encountered within the average operational month, and it may permit a more precise differentiation between the tasks performed within a trade, since such precision is not necessarily obtained using simple task difficulty or frequency ratings alone. Table 3 summarises these three subjective ratings for 10 land-based, materials-handling tasks.

From Table 3, it becomes apparent that handling the air compressor was the most difficult task. However, its frequency of operational handling meant that its cumulative stress, within an average month, was only about 59% of that encountered when handling a 55-HP outboard motor on land. Therefore, a first-level task prioritisation, based upon the combined treatment of difficulty and frequency, may be of greater value, and can be used to generate an initial task ranking, which will then be combined with more objective measures of stress and physiological strain. However, within a number of military trades, some low-frequency tasks can actually have a significant impact upon operational outcomes, so this combined treatment may need to be moderated, such that some alignment can occur between task stress and the operational significance of the task.

Physical measurement: Obtaining reliable physical assessments of each task, the equipment used when performing the task (e.g. dimensions, mass, centre of gravity, symmetry, position of carry points), load movement descriptors (e.g. required range of motion, leverage, movement velocity, stability during movement), and the working environment (e.g. dimensions of space, posture, lighting, noise, vibration, floor surface or terrain, climate, protective clothing, operational urgency), permits the assignment of an absolute task-related stress upon the worker (demand). Equipment inspections can vary in complexity from a complete analysis through to simple measurements of equipment, followed by observations of people working with, or lifting and carrying, each item.

To illustrate the latter, the typical operational loadout for Clearance Divers required more than 1,500 items (total mass >43,000 kg) to be lifted, or lowered, vertically 1.5 m from the ground to truck tray height, during the Base loadout. However, in the field, the majority of these items are routinely transported to a beach landing in an inflatable boat, then carried by the divers to their operation Base, with the typical carriage distance being 120 m. These carriages included nine different items weighing 200 kg or more. These materials-handling tasks may be undertaken on soft sand, on uneven surfaces, under considerable climatic stress, and while wearing various forms of protective clothing (Taylor et al., 2000).

Physiological measurement: Quantification of physiological strain facilitates an understanding of both the absolute (supply) and relative strain experienced when performing the task. To evaluate relative strain, one must also quantify the upper limits (power and capacity) of each physiological attribute, under relevant test conditions.

Criterion-referenced performance: Physiological testing should be performed using trained workers, and not recruits, with a mix of “poor”, “good” and “superior” performers. This not only permits quantification of the physiological attributes commensurate with ideal task performance (precise, reproducible and efficient), but also the strain, and possible consequences, associated with failing to satisfy this standard. To prevent systematic sampling errors, resulting in the analysis of unrepresentative individuals, and skewed outcomes, it is essential to evaluate workers from a wide range of body shapes and sizes, and, in trades where both genders are represented, a gender balance within the workers studied must be established. Task performance can then occur under both typical and, where appropriate, extreme operational conditions.

Using this criterion-referenced method, a two-phase approach to physiological observation is recommended. In the

<table>
<thead>
<tr>
<th>Task Description</th>
<th>Difficulty</th>
<th>Frequency</th>
<th>Stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>Truck loading and unloading</td>
<td>6.4 (2.0)</td>
<td>5.7 (5.9)</td>
<td>33.5</td>
</tr>
<tr>
<td>Zodiac handling</td>
<td>6.4 (1.5)</td>
<td>9.9 (7.9)</td>
<td>63.4</td>
</tr>
<tr>
<td>Zodiac outboard handling</td>
<td>6.9 (1.7)</td>
<td>9.2 (6.6)</td>
<td>61.3</td>
</tr>
<tr>
<td>Mine lifting bag handling</td>
<td>5.8 (1.8)</td>
<td>4.8 (5.9)</td>
<td>25.3</td>
</tr>
<tr>
<td>“Jackstay” handling</td>
<td>7.5 (1.9)</td>
<td>3.6 (3.8)</td>
<td>26.7</td>
</tr>
<tr>
<td>Compressor handling</td>
<td>8.2 (1.9)</td>
<td>5.0 (4.7)</td>
<td>36.0</td>
</tr>
<tr>
<td>Diver “stomping”</td>
<td>6.8 (1.8)</td>
<td>5.0 (4.7)</td>
<td>26.1</td>
</tr>
<tr>
<td>Chain block handling</td>
<td>6.1 (1.7)</td>
<td>3.5 (5.8)</td>
<td>17.8</td>
</tr>
<tr>
<td>Welding equipment handling</td>
<td>5.7 (1.6)</td>
<td>2.7 (2.8)</td>
<td>15.0</td>
</tr>
<tr>
<td>Bomb suit handling</td>
<td>5.6 (1.7)</td>
<td>3.2 (3.0)</td>
<td>12.8</td>
</tr>
</tbody>
</table>

Notes: Data are means, with standard deviations within parenthesis.
first phase, various physiological measurements may be performed on people completing the trade tasks. For example, measures of heart rate and oxygen consumption may be used to evaluate cardiovascular and metabolic strain, force generation and electromyographic observations may be used to assess muscular loads and strain, body tissue temperatures reflect thermal strain, and psychophysical indices, which are often affected by several physiological variables, provide useful information related to the perception of effort. In the second phase, the tasks are assessed according to their involvement of the general physical fitness attributes (e.g. whole-body endurance, strength, power).

Cardiovascular strain: To illustrate phase one, we shall present the heart rate response of a dive Officer during a simulated explosive ordinance disposal (Figure 2). Overlayed onto the tracing are the measured heart rate zones corresponding to 70%, 80% and 100% of this subject’s maximal heart rate. The combination of these data permit a more detailed treatment of the heart rate response, so that cardiovascular strain may be evaluated in four forms: the average heart rate observed whilst performing the task; the peak heart rate over the time of observation; the cardiovascular impulse (product of average heart rate and time); and the weighted cardiovascular load (ratio of average heart rate to resting heart rate, multiplied by the task duration).

It is important to note, however, that environmental factors modify the heart rate responses. For instance, while heat elevates heart rates at any given workload, whole-body submergence and breathing gas mixtures containing high oxygen partial pressures act to suppress the exercising heart rate. Heart rate is also higher for upper-body, compared with lower-body work. Thus, some caution needs to be exercised when comparing these data across different forms of work and different environmental conditions.

Each of these different cardiovascular indices provide useful information concerning the physiological strain experienced by the worker. However, neither the average nor the peak heart rates are time referenced. Thus, while one can compare relative task intensities using the average heart rate responses, these data are unidimensional, and tell very little about the cumulative physiological strain. The cardiovascular impulse is time sensitive, being similar to an integrated measure, but can provide very large numbers, which may be of limited relevance within the applied field, where work times may vary markedly between tasks. Thus, these indices are more useful for tasks of similar duration. Accordingly, some manipulation, such as the weighted cardiovascular load, may be more useful. Since it is the heart rate elevation above rest which is of primary interest,
this index was designed to allow one to compare the duration-specific strain of raising the heart rate above resting level. Each of these treatments are summarised in Table 4.

The merit of the cardiovascular load derivation is apparent when one considers the failure of either the average or maximal heart rates to adequately differentiate between some of the tasks performed by the Clearance Divers (Table 4). For example, when one compares the land-based carriage of the “jackstay” cruciforms and a Zodiac, a four-beat difference in average heart rate during the task masked the almost three-fold difference of cardiac strain revealed within the cardiovascular load data.

Since the cardiovascular load index is derived relative to resting heart rate alone, it does not provide information relating to the heart rate reserve of the individual. For example, a diver with a resting heart rate of 65 b·min⁻¹, working at an average heart rate of 130 b·min⁻¹ for a duration of 1 min will have a cardiovascular impulse of 2, indicating a two-fold elevation in heart rate. While it is certainly correct that all tasks which elevate heart rate also elicit a degree of cardiovascular strain, a more sensitive strain index may be provided by incorporating information relating to the upper limit to which this strain may be increased, how closely the heart rate approaches this upper limit, and the duration for which this elevation is held.

To provide this information, heart rate reserve target zones may be determined, as can the absolute and relative times spent within each of these target zones, during task performance. Examples of these data are summarised in Table 5. We recommend that both the general approaches be used to quantify cardiac strain. By comparing the data in Tables 4 and 5, one can now identify and rank the most stressful tasks, on the basis of cardiac strain.

**Physical fitness classifications:** Using an array of physical and physiological measurements, it becomes possible to assess each tasks according to its physical fitness attributes. That is, the relative contributions of the following fitness components can be determined: general (whole-body) endurance; local muscle endurance; strength; speed; power; flexibility; coordination; and agility. While there is some degree of subjectivity in this stage of the evaluation, the scientist, through careful observation and valid measurements, is able to make sound, well-considered and scientifically-justified assessments.

For the 18 tasks evaluated for the RAN Clearance Divers, four attributes were dominant: general endurance; local muscle endurance; strength; and power (Taylor et al., 2000). In descending order, according to the number of tasks in which each attribute was considered to be the primary physical fitness attribute, the following fitness ranking was obtained: strength (44%); local muscle endurance (34%); general endurance (22%). This information not only forms the basis upon which a trade screening test may be based, but it is also fundamental primary source material for the development of work-based physical fitness training programmes.

5) **Validation**

The procedures described above will generally lead to the establishment of high content and concurrent validities within
both trade analyses and the development of trade screening
tests. However, additional testing may be required to either
quantify, or to verify that both the predictive and construct
validities are acceptably high.

Projected Trade Analysis Outcomes

After the task elements and attributes have been evaluated
using the model above, ten general outcomes may be expected
from a thorough trade analysis:

(i) typical task performance durations;
(ii) mean monthly frequencies of task performance;
(iii) mean subjective difficulty ratings of personnel for
each task;
(iv) mean cumulative stress of each task;
(v) primary movement actions involved in completing
each task;
(vi) major muscle groups involved within each task;
(vii) physiological strain measurements for each task;
(viii) a psychophysical assessment (e.g. effort sense)
associated with performing each task;
(ix) primary, secondary and tertiary physical fitness
classifications for each of the tasks observed; and
(x) a generic summary of the trade tasks which includes
the relative frequencies and contributions of each of
the above components to the physically-demanding
components of the trade.

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