Kommission
Arbeitsschutz und
Normung

Biomechanical thresholds

A study to support standardization work on collaborative robots ("cobots")

Biomechanische Belastungsgrenzen

Studie zur Unterstützung der Normungsarbeit im Bereich der kollaborierenden Roboter

Limites de contraintes biomécaniques

Étude visant à aider le travail de normalisation dans le domaine des robots collaboratifs

Verein zur Förderung der Arbeitssicherheit in Europa e.V.

Kommission Arbeitsschutz und Normung

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Kommission Arbeitsschutz und Normung

Inhalt

Zu dieser Studie

Die Kommission Arbeitsschutz und Normung (KAN) hat den Auftrag, die deutschen Arbeitsschutzinteressen in der nationalen, europäischen und internationalen Normung zu wahren und die Beteiligung der Sozialpartner an der Normung zu gewährleisten. Dabei verfolgt sie das Ziel, dass nicht nur die deutsche und europäische, sondern auch die internationale Normung den Arbeitsschutz bestmöglich berücksichtigt. Die KAN setzt sich aus je fünf Vertretern der Arbeitgeber, der Arbeitnehmer, des Staates, sowie aus je einem Vertreter der Deutschen Gesetzlichen Unfallversicherung (DGUV) und des DIN Deutsches Institut für Normung e.V. zusammen. Um arbeitsschutzrelevante Sachverhalte in der Normung zu analysieren und den Verbesserungsbedarf in der Normungsarbeit zu ermitteln, vergibt die KAN unter anderem Studien und Gutachten.

Hintergrund

Bisher konnten Roboter nur Aufgaben im Automatikbetrieb übernehmen, die vollständig ohne Personeneinsatz möglich sind. Dies liegt daran, dass die bisher gültigen Arbeitsschutzvorschriften keinen Zugang von Personen in die Nähe von automatisch gesteuerten Robotern erlauben. Insbesondere Montageaufgaben ließen sich jedoch oft nicht automatisieren, weil einzelne Tätigkeiten nicht ohne die Hilfe von Menschen auskommen. Damit neuartige gemeinsame Arbeitsbereiche für Menschen und Roboter geschaffen werden können, müssen sichere Roboter eingesetzt werden, von deren Bewegungen auch ohne trennende Schutzeinrichtungen keine unmittelbaren Gefahren ausgehen. Ein wesentlicher Baustein dieser sicheren Roboter ist eine sichere Steuerung, die alle Bewegungen gezielt überwacht, indem sie die Bewegungen des Menschen erkennt und ihm ausweichen kann. Da ein direkter Kontakt zwischen Roboter und Person trotzdem möglich ist, bleibt im Gegensatz zu trennenden Schutzeinrichtungen ein geringes Risiko einer Kollision bestehen. Die Beanspruchungseffekte durch Kollision müssen daher so begrenzt werden, dass nur geringe, tolerable Verletzungsschweren auftreten können.

Das hat zur Folge, dass die Risikobeurteilung des Roboterherstellers den vorgesehenen betrieblichen Einsatz einschließen muss. Grundlage dieser Risikobewertung ist neben der Maschinenrichtlinie die EN ISO 10218:2011, Teil 1[1] und 2[2]. Diese Normen beinhalten zurzeit keine ausreichenden sicherheitstechnischen Anforderungen an eine Bewertung des Risikos einer Kollision, die durchaus häufiger auftreten

[1] „Industrieroboter - Sicherheitsanforderungen - Teil 1: Roboter“

[2] „Industrieroboter - Sicherheitsanforderungen - Teil 2: Robotersysteme und Integration“

kann. Die tolerablen Folgen einer Kollision könnten bei einer Risikobewertung im Gegensatz zu den bekannten reversiblen Folgen (Schadensparameter S1) und irreversiblen Folgen (S2) mit „S0“ klassifiziert werden.

Das Institut für Arbeitsschutz der Deutschen Gesetzlichen Unfallversicherung (IFA) hat zusammen mit dem Fachausschuss Maschinenbau, Fertigungssysteme, Stahlbau[3] Empfehlungen erarbeitet, die technologische, medizinisch-biomechanische, ergonomische und arbeitsorganisatorische Anforderungen an Arbeitsplätze mit kollaborierenden Robotern beinhalten. Weiterhin enthalten die Empfehlungen orientierende Grenzwerte für die maximal erlaubten Verletzungsschweren. Die Ergebnisse dieses Forschungsvorhabens des IFA sollen validiert und ggfs. optimiert werden, um dann in die harmonisierte Roboternorm EN ISO 10218-2 einfließen zu können.

Die skizzierte Problematik im Bereich der kollaborierenden Roboter hat eine große allgemeine Bedeutung für viele mechanische Mensch-Maschine-Schnittstellen. Die betroffenen Kreise der UVT sind daher sehr daran interessiert, neben den Erkenntnissen auf dem Gebiet der Roboterkollision auch Ergebnisse zu biomechanischen Belastungsgrenzen für die mechanische Risikobeurteilung allgemein zu bekommen. Bisher liegt hier nichts Vergleichbares, aus der Sicht des Arbeitsschutzes Bewertetes vor.

Ziel der Studie

Die Studie soll als erster Schritt dazu dienen, den aktuellen Stand und weiteren Bedarf an Grundlagen zur mechanischen Risikobeurteilung zu erarbeiten. Dies soll im Hinblick auf die Einordnung von Verletzungsbefunden und biomechanischen Verletzungskriterien in Schadensschwerekategorien geschehen.

Auf den Ergebnissen dieser Studie aufbauende spätere Arbeiten sollen letztendlich helfen, Arbeitsschutzexperten und Herstellern eine Datenbasis bei konkreten Problemstellungen in Risikobewertungen und die Gewissheit zu geben, dass im Bereich des Arbeitsschutzes konforme Entscheidungen bei der mechanischen Risikobeurteilung getroffen werden.

Die im Folgenden benutzten Begriffe „Belastungsgrenze“ und „Verletzungskriterium“ sind als Synonyme zu betrachten.

[3] heute: Sachgebiet „Maschinen, Anlagen, Fertigungsautomation und -gestaltung“ des Fachbereichs „Holz und Metall“ der DGUV

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About this report

The Commission for Occupational Health and Safety (KAN) has the mandate of safeguarding German occupational safety and health interests in national, European and international standardization activity, and of assuring the participation of the social partners in standardization. It therefore pursues the objective of ensuring that the best possible consideration is given to OSH issues in not only German and European but also international standardization. KAN comprises five representatives each from employers’ organizations, employees’ organizations and the state, and one representative each from the German Social Accident Insurance (DGUV) and the DIN German Institute for Standardization.
KAN analyses OSH-related issues in standards and scope for improvement in standardization work. One means by which this is achieved is the commissioning of studies and reports.

Background

As current OSH regulations do not allow people in the proximity of automatically controlled robots, such robots can only be used for automated tasks that do not require any human involvement. However, certain tasks, especially on assembly lines, cannot be performed without human assistance, making automation impossible in many cases. New collaborative workspaces for humans and robots will require safe robots whose movements do not pose a direct hazard even if guards are not used. Reliable control systems that prevent the robot colliding with the worker by monitoring all of the movements that occur will be a key component in these safe robots. However, since there is still a possibility of direct contact between the robot and the person in such collaborative workspaces, there remains a small risk of collision that is absent when guards are used. Consequently, the biomechanical strains caused by a collision need to be limited to an extent that only permits low, acceptable levels of injury severity.

Given that need, robot manufacturers' risk assessments must also cover the intended use in the workplace. These risk assessments are based on the Machinery Directive and on EN ISO 10218:2011, Parts 1[4] and 2[5]. The current versions of these standards do not contain adequate requirements in relation to collision risk assessment - a risk that is not uncommon. Risk assessments could classify ac-

[4] "Safety requirements for industrial robots - Part 1: Robots"

[5] "Safety requirements for industrial robots - Part 2: Robot systems and integration"

ceptable collision injuries as "S0" to distinguish them from the established categories of "S1" for reversible injuries and "S2" for irreversible injuries.

In a joint project, the DGUV Institute for Occupational Safety and Health (IFA) and the Expert Committee on Mechanical Engineering, Manufacturing Systems and Structural Steel Engineering[6] drew up recommendations for technological, medical, biomechanical, ergonomic and organisational requirements for workplaces with collaborative robots. The recommendations also include indicative injury severity thresholds. The findings of this IFA research project are to be validated and optimized as necessary before being incorporated into the harmonized robot standard, EN ISO 10218-2.

The issues outlined above are of major relevance in a whole range of mechanical human-machine interfaces. The stakeholders represented in the German social accident insurance institutions that deal with cobots are therefore extremely keen to obtain information not just about collisions with robots but also about biomechanical thresholds, which can be used in assessing mechanical risk. As yet, there are no research findings on this topic that have been evaluated for OSH purposes.

Objective of this study

This study is intended to provide an initial review of the current situation and the need for additional criteria with which to assess mechanical risks. The objective is to classify injury diagnoses and biomechanical injury criteria in injury severity categories.

The findings of this study are to inform subsequent activities, which will ultimately serve to provide OSH experts and manufacturers with a pool of data to help them tackle risk assessment problems and ensure consistent decision-making in the area of mechanical risk assessment.

The terms "threshold" and "injury criterion" are used synonymously in the following.

[6] Now known as the "Machinery, plants, automation and design of manufacturing systems" sub-committee of the "Woodworking and metalworking" expert committee of the DGUV

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À ce propos

La Commission pour la sécurité et la santé au travail et la normalisation (KAN) a pour mission de défendre les intérêts allemands en matière de sécurité et de santé au travail dans la normalisation nationale, européenne et internationale, et de garantir la participation des partenaires sociaux à la normalisation. Son objectif, dans ce contexte, est de veiller à ce que les enjeux de la prévention soient pris en compte le mieux possible dans la normalisation, non seulement allemande et européenne, mais aussi internationale. La KAN se compose de représentants des employeurs, des employés et de l'État (cinq membres chacun), ainsi que d'un représentant chacun de l'Assurance sociale allemande des accidents du travail et maladies professionnelles (DGUV) et de l'Institut allemand de normalisation (DIN).
La KAN commissionne, entre autres, des études et expertises destinées à analyser les aspects de la normalisation ayant une incidence sur la sécurité et la santé au travail et à déterminer les améliorations nécessaires dans le travail de normalisation.

Contexte

Jusqu'ici, les robots pouvaient effectuer uniquement des opérations automatisées sans aucune intervention humaine. Ceci est dû au fait que la législation relative à la sécurité au travail en vigueur jusqu'ici n'autorise pas les personnes à s'approcher de robots à commande automatique. Or, il arrive souvent que certaines opérations, en particulier d'assemblage, ne puissent pas être automatisées, mais nécessitent également l'intervention d'un opérateur. Pour pouvoir créer de nouvelles zones de travail communes pour l'homme et le robot, il faut utiliser des robots sûrs dont les mouvements ne présentent aucun risque direct, même sans protecteurs. L'un des composants fondamentaux de ces robots sûrs est un système de commande sûr qui en surveille tous les mouvements de manière ciblée en reconnaissant les mouvements des personnes pour pouvoir les éviter. Étant donné qu'un contact direct entre le robot et la personne reste tout de même possible, un faible risque de collision subsiste, contrairement aux protecteurs. Les effets des astreintes entraînées par une collision doivent être si limités que les seules blessures susceptibles de se produire seront bénignes et tolérables.

L'évaluation du risque devant être réalisée par le fabricant du robot doit donc prendre en compte l'utilisation prévue. Cette évaluation du risque repose sur la directive Machine, mais aussi sur la norme EN ISO 10218:2011, parties 1[7] et 2[8]. Ces normes

[7] « Robots et dispositifs robotiques – Exigences de sécurité pour les robots industriels – Partie 1: Robots »

n'évoquent actuellement pas d'exigences de sécurité suffisantes concernant une évaluation du risque d'une collision qui peut tout à fait avoir lieu plus fréquemment qu'on le croit. Les conséquences tolérables d'une collision pourraient être classifiées dans une évaluation du risque dans une catégorie « S0 », contrairement aux conséquences réversibles (paramètre de dommage S1) et aux conséquences irréversibles (S2) connues.

L'Institut pour la sécurité et la santé au travail de la DGUV (IFA) a élaboré en collaboration avec le comité technique Génie mécanique, systèmes de production, construction métallique[9] des recommandations contenant des exigences technologiques, médico-biomécaniques, ergonomiques et concernant l'organisation du travail sur les lieux de travail impliquant des robots collaboratifs. Ces recommandations établissent d'autre part des limites de tolérance indicatives pour les différents degrés de gravité des blessures maximaux autorisés. Les résultats de ce projet de recherche mené par l'IFA devront être validés et au besoin optimisés, afin de pouvoir les prendre en compte dans la norme harmonisée relative aux robots EN ISO 10218-2.

La problématique ébauchée dans le domaine des robots collaboratifs est d'une grande importance générale pour de nombreuses interfaces mécaniques homme-machine. Les organismes d'assurance accidents sociale concernés attendent donc avec grand intérêt de recevoir des conclusions en ce qui concerne la collision des robots, mais aussi d'une manière générale des résultats relatifs aux limites de contraintes biomécaniques pour l'évaluation du risque mécanique. On ne dispose jusqu'ici de rien de comparable évalué du point de vue de la prévention.

Objectif de l'étude

L'étude avait pour objet de servir dans une première mesure à faire un état des lieux de la situation actuelle et des besoins supplémentaires en principes fondamentaux pour l'évaluation du risque mécanique. Ceci devait être fait en tenant compte du classement des diagnostics et des critères biomécaniques des blessures dans des catégories de gravité des dommages.

Se basant sur les résultats de cette étude, des travaux ultérieurs devraient en fin de compte aider à fournir aux préventeurs et aux fabricants une base de données

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[8] « Robots et dispositifs robotiques – Exigences de sécurité pour les robots industriels – Partie 2: Systèmes robots et intégration »

[9] Actuellement : sous-section spécialisée « Machines, installations, automatisation et organisation de production » de la commission sectorielle « Bois et métal » de la DGUV

s'ils rencontrent des problèmes concrets lors de la réalisation d'évaluations du risque, et à leur donner l'assurance qu'ils prennent des décisions conformes dans le domaine de la prévention lorsqu'il réalisent leur évaluation du risque mécanique.

Les termes « limite de contrainte » et « critère de blessure » doivent être considérés comme synonymes.

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Zusammenfassung der KAN

Analyse der vorhandenen Literatur

a) Für die Recherche wurden neben frei zugänglichen auch die kostenpflichtigen Datenbanken und –bestände (Informationsmittel) verwendet, die während der Studiendauer der Fraunhofer-Gesellschaft und der Bibliothek der Otto-von-Guericke-Universität zur Verfügung standen. Aus diesen (insgesamt über 7000) wurden 245 für die Zwecke der Studie erfolgversprechende Informationsmittel durchsucht. Daraus sind wiederum 1036 Titel in eine eigene Datenbank übernommen worden. Diese Datenbank basiert auf der Software CITAVI, mit der Literatur und vergleichbare Medien strukturiert abgelegt und verwaltet werden können. Aufgrund der begrenzten Bearbeitungszeit konnten nicht alle Titel gesichtet werden. Vor der Exzerption wurde daher zunächst die Relevanz der Titel bewertet.

b) In der Reihenfolge dieser Relevanz sind dann insgesamt 407 Titel gesichtet worden. Davon wurden aus 100 Titeln konkrete Belastungs-Beanspruchungs-Relationen exzerpiert und in eine ACCESS-Datenbank übernommen. Diese exzerpierten Titel wurden technisch (Versuchsaufbau und messtechnische Herangehensweise) und medizinisch (medizinische Beschreibung und Untersuchung der Beanspruchung) bewertet. In der ACCESS-Datenbank wurden zu den 100 Titeln 560 Belastungs-Beanspruchungs-Relationen übernommen, denen 1587 gemessene Belastungswerte (messbare, physikalische Größen) zugeordnet sind. Über eine Exportfunktion kann zu jedem Titel aus dieser Datenbank ein Datenfaktenblatt erstellt werden, das alle Informationen zu den Belastungs-Beanspruchungs-Relationen enthält. Darüber hinaus ist es möglich, weitere Titel in die Datenbank zu übernehmen.

c) Unter den 100 Titeln in der ACCESS-Datenbank haben lediglich 57 eine hohe Arbeitsschutzrelevanz. Davon entstammen allein 20 Titel aus dem Bereich der Normung bzw. Regelsetzung, das heißt, dass darin keine wissenschaftliche Begründung für die festgelegten Grenzwerte gegeben wird. Somit sind nur 37 von 407 gesichteten Titeln für die Beurteilung des derzeitigen wissenschaftlichen Forschungsstandes zur mechanischen Risikobeurteilung von kollaborierenden Robotern relevant. Dies zeigt, wie gering der Umfang an Forschungsarbeiten für nutzbare Grenzwerte in diesem Bereich ist.

Kategorisierung „leichter“ Verletzungen

a) Viele der existierenden Skalen, Scores und Codierungen von Verletzungsschweren beinhalten nicht den im Fokus der Studie liegenden Bereich der „leichten Verletzungen“. Zudem konnte nur bei wenigen Skalen, Scores und Codierungen festgestellt werden, ob sie anerkannt und weit verbreitet sind. Im Verlauf der Studie wurden lediglich zwei Codierungssysteme identifiziert, die in mehreren der recherchierten Titel für die Einordnung von Verletzungen herangezogen wurden. Aufgrund der beachtenswerten Vollständigkeit und weltweiten Verbreitung eignet sich Teil XIX der internationalen statistischen Klassifikation der Krankheiten und verwandter Gesundheitsprobleme (International Statistical Classification of Diseases and Related Health Problems, ICD) „Verletzungen, Vergiftungen und bestimmte andere Folgen äußerer Ursachen" am besten für die Beschreibung von Verletzungsbildern im Arbeitsschutz.

b) Eine neue Schadensschwerekategorie S0 (anknüpfend an die in der Maschinensicherheit etablierten Kategorien S1 und S2) sollte als neuer Bereich unterhalb der bestehenden Kategorie S1 eingeführt werden. Sie sollte jedoch nur für bestimmte, eng eingegrenzte Anwendungsfälle herangezogen werden dürfen.

c) Zu der Verletzungsschwerekategorie S0 zählen ausschließlich oberflächliche Verletzungen, die auch ohne medizinische Behandlung *folgenlos* ausheilen. *Eine Durchdringung der Oberhaut ist **nicht** zulässig und daher von dieser Kategorie ausgenommen*. Zum Beispiel würde eine leichte Prellung am Unterarm ohne Verletzung der Oberhaut als S0 klassifiziert werden, wohingegen eine Schürfwunde am Handballen S1 sein würde. Eine konkrete Zuordnung der zugehörigen Verletzungen erfolgt auf Grundlage der ICD.

Strukturierung von biomechanischen Belastungsgrenzen

a) Es ließ sich nur eine physikalische Größe bestimmen, die einen *alleinigen* Einfluss auf eine spezifische Beanspruchung hat: die Entstehung von Frakturen wurde in allen betreffenden Titeln einheitlich mit der Größe „Kraft" bemessen. Es konnten jedoch keine physikalischen Größen benannt werden, mit denen sich biomechanische Belastungen *allgemein* und sinnvoll *für alle denkbaren* Beanspruchungen und Lokalisationen begrenzen lassen. Gerade für singuläre Belastungsereignisse wurde festgestellt, dass die ausschlaggebenden Belastungsgrößen und deren Kombinationen für zahlreiche Beanspruchungen nicht bekannt sind.

b) In der Regel können bis zu drei unterschiedliche Größen und Parameter die Entstehung und/oder Ausprägung einer Beanspruchung beeinflussen. Es wurde für die Strukturierung biomechanischer Belastungsgrößen eine Abbildung entwickelt, mit der sich bis zu drei Einflussgrößen grafisch darstellen lassen. Wie in einem Koordinatensystem kann damit anhand der wertemäßig vorliegenden Einflussgrößen und Parameter die zu erwartende Beanspruchung abgelesen werden.

Summary by KAN

Literature review

a) The literature review was carried out using the databases and information sources available to the Fraunhofer Society and the library of Otto-von-Guericke University during the study (both those that were free of charge and those for which a fee was payable). From these sources (totalling more than 7,000), 245 that were felt to be of interest for the study were analyzed, yielding a total of 1,036 literature sources, which were then stored in the study database. The database uses CITAVI, a software package for organising and managing literature and similar media. As time constraints made it impossible to review all of the literature sources, they were assessed for relevance prior to excerption.

b) A total of 407 literature sources were then reviewed in order of relevance. Stress-strain relationships were extracted from 100 of them and then incorporated into an ACCESS database. The excerpted sources were evaluated from a technical (experiment set-up and measuring method) and medical (medical description and examination of the strain) point of view. 560 stress-strain relationships, with 1,587 strain measurements (measurable, physical parameters), were incorporated from the 100 sources into the ACCESS database. Using the export function, fact sheets containing all of the data concerning the stress-strain relationships can be created for each of the sources in the database. It is also possible to add further literature sources to the database.

c) Of the 100 literature sources in the ACCESS database, only 57 are particularly relevant in terms of safety and health. Of those, a whole 20 are from the fields of standardization and regulation, i.e. they do not provide any scientific grounds for the defined thresholds. Consequently, only 37 of 407 reviewed literature sources are relevant when assessing the current state of research on mechanical risk assessment for cobots. These figures show how little research has been done to produce practical threshold values for this field.

Categorisation of "minor" injuries

a) Many of the existing scales, scores and coding systems for injury severity do not cover minor injuries, which are the focus of this study. Moreover, it was only possible in just a few cases to determine the extent to which they are recognized and in widespread use. The study only identified two coding systems that several of the reviewed sources employed for injury classification. The system most suitable for describing injuries in the OSH field (due to its remarkably exhaustive nature and worldwide use) is that presented in Chapter XIX of the International Statistical

Classification of Diseases and Related Health Problems (ICD), which deals with "Injuries, poisoning and certain other consequences of external causes".

b) A new injury severity category, S0 (in line with the S1 and S2 categories that have become established in machinery safety), should be introduced as a new level, below S1. However, it should only be permitted for a specific set of narrowly defined cases.

c) The S0 injury severity category would only include superficial injuries that heal *completely* without any medical treatment. *Skin breakage would* ***not*** *be permitted and would therefore be excluded from this category*. For example, a minor contusion on the lower arm without any skin damage would be classified as S0 but a graze on the ball of the hand would be S1. Any injuries would be classified on the basis of the ICD.

Structuring of biomechanical thresholds

a) The study only identified one physical parameter that was the *sole* parameter to influence a specific type of strain - "force", which all of the relevant literature sources used to measure fracturing. It proved impossible, however, to find any physical parameters for limiting biomechanical stresses that would be *generally applicable* and practical *for all conceivable* strains and localisations. In particular, it became clear that, in many cases, there was no information as to the (combinations of) factors that trigger one-off stress events.

b) Generally speaking, up to three different factors can influence the development and/or degree of a strain. A chart was developed to enable up to three factors to be visualised for the purpose of structuring biomechanical stresses. Much like a coordinates system, it can be used to derive the probable strain based on the known parameters and factors.

Résumé de la KAN

Analyse de la littérature existante

a) On a utilisé pour les recherches effectuées des bases et collections de données gratuites et payantes (supports d'information) disponibles pour toute la durée de l'étude auprès de la Société Fraunhofer et la bibliothèque de l'université Otto von Guericke. Parmi ces supports d'information (7 000 au total), 245 d'entre eux, très prometteurs pour l'étude, ont été étudiés. 1 036 ouvrages en ont été extraits et intégrés dans une base de données interne. Cette base de données a été créée à l'aide du logiciel CITAVI qui permet d'archiver et d'administrer des ouvrages littéraires et autres supports similaires de manière structurée. Le temps imparti à l'étude limité n'a pas permis de passer tous les ouvrages disponibles en revue. La pertinence de chaque ouvrage a donc d'abord été évaluée avant d'en tirer des extraits.

b) 407 ouvrages au total ont alors été passés en revue par ordre de pertinence. Sur ces 407 ouvrages, des relations contrainte-astreinte concrètes ont été extraites de 100 ouvrages et reprises dans une base de donnée ACCESS. Ces ouvrages extraits ont fait l'objet d'une évaluation technique (montage d'essai et approche de mesure) et médicale (description médicale et analyse de l'astreinte). Dans la base de données ACCESS, 560 relations contrainte-astreinte ont été intégrées par rapport à ces 100 ouvrages et 1 587 valeurs de contrainte mesurées y ont été assignées (grandeurs physiques mesurables). Une fonction d'exportation permet de générer pour chaque ouvrage contenu dans cette base de données une fiche d'informations reprenant toutes les informations relatives aux relations contrainte-astreinte. Il est de plus possible d'ajouter d'autres ouvrages à la base de données.

c) Parmi les 100 ouvrages contenus dans la base de données ACCESS, seuls 57 sont particulièrement pertinents pour la sécurité et santé au travail. 20 de ces ouvrages étaient à eux seuls issus du domaine de la normalisation et de la réglementation, ce qui signifie qu'ils ne contenaient aucune justification scientifique pour les limites de tolérance fixées. Ainsi, seuls 37 des 407 ouvrages passés en revue sont d'un quelconque intérêt pour évaluer la situation actuelle de la recherche scientifique en matière d'évaluation du risque mécanique des robots collaboratifs. Ceci montre à quel point on dispose de peu de travaux scientifiques fournissant des limites de tolérance exploitables dans ce domaine.

Catégorisation des blessures « légères »

a) Beaucoup des échelles, indices et codifications existants pour classer la gravité des blessures ne comportent pas le domaine des « blessures légères » sur lequel l'étude se concentre. De plus, il a pu être constaté que quelques-unes seulement de ces échelles, indices et codifications sont reconnus et largement répandus. Au cours de l'étude, seuls deux systèmes de codification ont pu être identifiés comme étant pris en compte pour catégoriser les blessures dans plusieurs des ouvrages passés en revue. En raison de sa remarquable exhaustivité et de son degré de diffusion dans le monde entier, le chapitre XIX de la classification statistique internationale des maladies et problèmes de santé connexes (CIM) intitulé « Lésions traumatiques, empoisonnements et certaines autres conséquences de causes externes » convient le mieux pour décrire les blessures dans le domaine de la prévention.

b) Une nouvelle catégorie de gravité des dommages S0 (se basant sur les catégories S1 et S2 établies dans le domaine de la sécurité des machines) devrait être introduite comme nouveau domaine après la catégorie S1 déjà existante. Elle ne doit néanmoins ne pouvoir être prise en compte que dans certains cas d'application particuliers très limités.

c) Les blessures appartenant à la catégorie de gravité des blessures S0 sont exclusivement les blessures superficielles qui peuvent guérir *sans conséquences* sans traitement médical. *L'épiderme* ***ne doit pas*** *être pénétré et tout type de blessure de ce genre sera donc exclu de cette catégorie*. Par exemple, une légère contusion à l'avant-bras sans lésion épidermique serait classée dans la catégorie S0, tandis qu'une écorchure de l'éminence thénar le serait dans la catégorie S1. Les blessures sont classées concrètement sur la base de la CIM.

Structuration des limites de contraintes biomécaniques

a) Une seule grandeur physique ayant une influence *exclusive* sur une astreinte spécifique a pu être déterminée : l'apparition de fractures a été définie de manière uniforme dans tous les ouvrages en question à l'aide de la grandeur « Force ». Il a été néanmoins impossible de désigner une grandeur physique permettant de limiter les contraintes biomécaniques *de manière générale* et judicieuse *pour toutes les astreintes et localisations imaginables*. Pour les contraintes singulières en particulier, il a été constaté que les grandeurs de la contrainte déterminantes et leurs combinaisons restent inconnues pour de nombreuses astreintes.

b) D'une manière générale, jusqu'à trois grandeurs et paramètres différents peuvent influencer l'apparition et/ou l'intensité d'une astreinte. On a développé pour la structuration des grandeurs de contraintes biomécaniques une représentation qui permet de représenter graphiquement jusqu'à trois grandeurs d'influence. Comme dans un système de coordonnées, on peut ainsi y lire l'astreinte attendue à l'aide des valeurs connues des grandeurs d'influence et des paramètres.

Empfehlungen der KAN

Die KAN beauftragt die KAN-Geschäftsstelle:

- Die Ergebnisse als KAN-Studie zu veröffentlichen.
- Den KAN-Studie ins Englische zu übersetzen.
- Die Access-Datenbank zusammen mit einer leicht verständlichen Anleitung auf den Webseiten der KAN zugänglich zu machen.

Die KAN bittet das DIN:

- Die Ergebnisse dieser Studie den betroffenen Normungsgremien zur Verfügung zu stellen.

Die KAN bittet die DGUV:

- Die Forschung zu Belastungs- und Beanspruchungsmodellen für die Kategorien S0 und H weiterhin zu fördern.
- Für zukünftige Normungsprojekte die Anwendbarkeit der neuen Schadensschwerekategorien S0 und H zu prüfen. Dabei ist sicherzustellen, dass zu der Verletzungsschwerekategorie S0 ausschließlich oberflächliche Verletzungen zählen, die auch ohne medizinische Behandlung folgenlos ausheilen. Eine Durchdringung der Oberhaut ist nicht zulässig und daher von dieser Kategorie auszunehmen. Unterhalb von S0 könnte darüber hinaus ein Unbedenklichkeitsbereich H eingeführt werden. Der Übergang dieses Bereichs zum Bereich S0 wäre durch die Schmerzschwelle definiert. Damit wäre es möglich, Belastungsereignisse, die keinen Schmerz hervorrufen, für die Risikobewertung als unbedenklich einzustufen.
- Wenngleich Schmerzforschung erforderlich ist, um Schwellenwerte zu ermitteln, darf für die Einteilung und Abgrenzung von Schadensschwerekategorien in Normen jedoch nicht vom Schmerz als Kriterium ausgegangen werden. In Normen mit Produktanforderungen ist vielmehr die zulässige Kraft zu benennen, die auf den Menschen einwirken darf; für wissenschaftlich noch nicht abgesicherte Bereiche bedeutet dies, dass dementsprechend angemessene Sicherheitsabschläge anzugeben sind.

Die KAN bittet die Bundesregierung:

- Die Forschung zu Belastungs- und Beanspruchungsmodellen für die Kategorien S0 und H in bestehende Förderprogramme aufzunehmen wie z.B.:
  - Forschung für die Produktion von morgen (Fachprogramm)
  - IKT 2020 - Forschung für Innovationen (Fachprogramm)
  - IKT 2020 - Wissenschaftliche Vorprojekte zur Mensch-Technik-Interaktion für den demografischen Wandel
  - InnoProfile-Transfer Förderung von Forschungsgruppen und Verbundprojekten
- Bei der Vergabe neuer Forschungsprojekte in den genannten Programmen sicherzustellen, dass darin auch die Untersuchung von Sicherheitsaspekten aufgenommen wird.

Die KAN bittet die Sozialpartner:

- Die Ergebnisse dieser Studie in ihren Kreisen bekannt zu machen.

Recommendations from KAN

KAN hereby instructs the KAN Secretariat:

- to publish the findings in the form of a KAN Study;
- to translate the KAN Study into English; and
- to make the Access database accessible on the KAN website, along with easy-to-understand instructions on how to use it.

KAN requests that DIN

- make the findings of this study available to the relevant standards committees.

KAN requests that DGUV

- continue to provide support for research on stress and strain models for the S0 and H categories;
- on future standardization projects, check whether the new injury severity categories of S0 and H could be used. It must be ensured, however, that the S0 injury severity category only includes superficial injuries that heal completely without any medical treatment. Skin breakage is not permitted and must therefore be excluded from this category. A "harmless" level (H) could also be introduced, below the S0 level. The crossover point between these two levels would be defined on the basis of the pain threshold. This would enable those stress events that do not cause any pain to be classified as harmless for the purposes of risk assessment;
- although pain research does need to be carried out in order to determine thresholds, pain must not be used as a criterion when classifying and defining injury severity categories in standards. Instead, standards that contain product requirements should cite the permissible force that may be exerted on an individual. This means that appropriate safety margins need to be given for those areas for which there are no reliable research findings as yet.

KAN requests that the Federal Government

- incorporate research on stress and strain models for the S0 and H categories into existing funding programmes, e.g.:
  - "Research for tomorrow's production" (specialized programme)
  - ICT 2020 - Research for innovation (specialized programme)
  - ICT 2020 - Preparatory research projects on human-technology interaction for demographic change

  - InnoProfile-Transfer funding for research groups and joint projects; and
- ensure that any new research projects assigned within the above programmes also include an examination of safety aspects.

KAN requests that the social partners

- share the findings of this study within their networks.

Recommandations de la KAN

Le Secrétariat de la KAN est chargé par la KAN :

- de publier les résultats dans une Étude KAN,
- de faire traduire l'Étude KAN en anglais,
- de donner accès à la base de données Access sur les sites Web de la KAN, accompagnée d'instructions faciles à comprendre.

La KAN demande au DIN :

- de fournir les résultats de cette étude aux comités de normalisation concernés.

La KAN demande à la DGUV :

- de continuer à promouvoir la recherche sur les modèles de contrainte et d'astreinte pour les catégories S0 et H.
- de vérifier l'applicabilité des nouvelles catégories de gravités des dommages S0 et H pour des projets de normalisation à venir. Il conviendra ici de vérifier que seules les lésions superficielles qui peuvent guérir sans conséquences sans traitement médical appartiennent à la catégorie de gravité des blessures S0. L'épiderme ne doit pas être pénétré et tout type de blessure de ce genre sera donc exclu de cette catégorie. Il serait d'autre part possible d'introduire une catégorie d'innocuité H qui suivrait la catégorie S0. Le passage de cette catégorie à la catégorie S0 pourrait dépendre du degré de la douleur. Il serait ainsi possible de considérer les contraintes ne provoquant aucune douleur comme étant sans risque pour l'évaluation du risque.
- Bien qu'il soit nécessaire de faire de la recherche sur la douleur pour pouvoir déterminer les valeurs de tolérances, on ne doit pas partir de la douleur comme critère pour définir et délimiter dans les normes les catégories de gravité des dommages. Dans les normes comportant des exigences relatives au produit, il faudra au contraire désigner la force maximale autorisée pouvant être appliquée sur les personnes, ce qui signifie pour les domaines pour lesquelles il n'existe pas encore de résultats de recherche validés qu'il faudra indiquer des marges de sécurité adéquates.

La KAN demande au gouvernement fédéral :

- d'intégrer la recherche sur les modèles de contrainte et d'astreinte pour les catégories S0 et H dans des programmes de financement existants tels que :
  - Recherche pour la production de demain (programme spécialisé)

  - IKT 2020 – Recherche pour les innovations (programme spécialisé)
  - IKT 2020 – Projets scientifiques préliminaires sur l'interaction homme-technique pour le changement démographique
  - InnoProfile-Transfer Promotion de groupes de recherche et de projets mixtes
- de s'assurer lors de l'attribution de nouveaux projets de recherche dans les programmes cités qu'ils intègrent également l'analyse des aspects de sécurité.

La KAN demande aux partenaires sociaux :

- de diffuser les résultats de cette étude dans leurs cercles.

KAN Study 52: Survey of biomechanical stress limits

A study conducted by the Fraunhofer Institute for Factory Operation and Automation IFF on behalf of the Commission for Occupational Health and Safety and Standardization (KAN)

Magdeburg, 18 November 2013

Last amended: 16 December 2013

Concluding report

Fraunhofer IFF

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IFR Institute of Forensic Medicine, Otto von Guericke University

Dr Katja Jachau
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Contents

Index of figures

Index of tables

1 Introduction

KAN study 52, Biomechanical stress limits, was launched specifically in order to support standardization activity in the field of collaborative robots. The first section of this Chapter provides a brief introduction to the current situation and to standardization activity in this field. This is followed by a section providing an overview of completed studies that are very similar to KAN Study 52. The final section presents the structure of the present concluding report.

1.1 Introduction

Conventional robots used in industrial production have long been appreciated for their fast and highly precise performance of monotonous, repetitive tasks. In future applications, this particular capacity is to be combined with the flexibility, fine motor control and intelligence of human beings, thereby yielding a range of benefits and new possibilities. Physical interaction between a human being and a robot, for example, enables processes to be implemented efficiently in which products are manufactured in a continually growing number of variants. Human-robot interaction is also a suitable means of relieving stress upon human operators.

Before now, the OSH regulations in force prevented or substantially constrained access by persons to automatically controlled multi-axis machines such as robots. In future however, new sensor and control technology will enable robots to monitor their environments and to react automatically to changes. In turn, this will enable the movements of a human being within a shared working space to be detected and analysed, in order for example for suitable evasion or braking operations to be initiated when a risk of collision is detected. However, many applications specifically require direct contact between the robot and the human being. It is not possible in this case to distinguish whether or not contact is intentional. A serious risk of dangerous contact (collision, crushing, etc.) therefore remains which could cause serious injury to the human being. For this reason, the biomechanical stress upon the human being in the event of unintended contact with a collaborative robot must be reduced such that the resulting strain level is acceptable.

The relevant standard, EN ISO 10218 [1] [2], is currently being revised for this purpose. The objective of the revision is for clear requirements to be formulated for the risk assessment of collaborative robot workstations. Before now, this standard did not contain adequate safety requirements for assessment of the risks associated with a collision. The German Social Accident Insurance Institutions call for injuries that are still tolerable to be clearly bounded in their classification from injuries with reversible (S1) and irreversible (S2) consequences.

The issue described here for the area of collaborative robots is also highly relevant to other areas involving mechanical human-machine interfaces. In the OSH lobby's view, no useful information has been available to date on biomechanical stress limits. KAN Study 52, Biomechanical stress limits, is to describe the current situation and to define the future need for principles governing biomechanical stress limits for the risk assessment of workstations involving mechanical human-machine interfaces.

1.2 Similar studies

The survey identified reports from three studies similar in background to the topic addressed in KAN Study 52:

HSE Research Report RR906 – Collision and injury criteria when working with collaborative robots. This study was conducted by the British Health and Safety Executive (HSE) and addressed the same topic as KAN Study 52. In the course of a literature survey, biomechanical stress limits were compiled suitable for use in occupational safety and health in the area of collaborative robots. The focus of the study lies firmly upon the content of the future ISO/TS 15066 standard, which at the time of KAN Study 52 (end of 2013) was being developed as a supplement to EN ISO 10218-2 [2]. The HSE study was to determine whether the strategies embodied in ISO/TS 15066 for the protection of human beings against mechanical stresses resulting from collision with a robot were adequate and realistic. Over 200 literature sources concerning human tolerance to injury and pain in relation to mechanical stress were studied. Worthy of mention is that at the time of the HSE study, a large proportion of the literature sources were used for the development of a standard governing protective clothing (CEN/TC 162). The concluding report of this study offers a wealth of information on the topic of biomechanical stress limits and thus constitutes an excellent supplement to the results of the KAN study [3].

NATO – Test methodology for protection of vehicle occupants against anti-vehicular landmine effects. A study conducted by the North Atlantic Treaty Organization compiled biomechanical stress limits for measurement of the strain suffered by occupants of a motor vehicle during detonation of an anti-vehicle mine. Limits were further derived for certain stress variables the effects of which lead to non-fatal injuries to various parts of the body [4].

University of Michigan, Transportation Research Institute, Review of biomechanical impact response and injury in the automotive environment. This study compiled biomechanical stress test results from research work that had been published by the end of 1984. In the concluding report of the study, the stress variables are divided between the following body regions: head, spine, thorax, abdomen, pelvis, and lower extremities. Each chapter is devoted to one of these body regions and provides information on the anatomy and clinical injury patterns and the results of experimental studies into biomechanical stresses. It should be noted that the focus of this study lay solely upon discrete stresses associated with car accidents [5].

Concluding reports of each of the three studies are available on the Internet for download.

1.3 Structure of the report

The present concluding report of KAN Study 52 is structured as follows:

Chapter 2: Structure and content of the study – This chapter contains all the information on organization of the study. This includes the schedule, introduction of the project partners, a definition of the agreed primary and secondary tasks, and their division into work packages and distribution of the tasks between the project partners.

Chapter 3**: Survey and excerption of sources –** This chapter describes the precise procedure followed during the study, and is divided into three sections. The first section describes preparation of the survey. The second section describes the selection and use of the tools required for the literature survey. The final section details and documents the excerption of the surveyed titles.

Chapter 4: Overall result of the study – This chapter contains the results of the study. The results of the survey are first presented statistically. A description then follows of the chief observations made during the survey in the individual subject areas and information resources. The results of the primary and secondary tasks of the study are also presented.

Chapter 5 summarizes the content of the concluding report. The literature survey can be found in Chapter 6. Information supplementing the results is compiled in the annex.

2 Structure and content of the study

This chapter provides an overview of the structure and content of the KAN study. The project partners are presented, the agreed tasks stated, and their division among the partners described.

2.1 Consortium

KAN Study 52, Biomechanical stress limits, was conducted by the Fraunhofer IFF and the Institute of Forensic Medicine of Otto von Guericke University. The two institutes are presented briefly below.

2.1.1 Fraunhofer IFF – Robotic Systems Business Unit

The Fraunhofer Institute for Factory Operation and Automation IFF in Magdeburg is an autonomous, decentralized scientific institution within the Fraunhofer-Gesellschaft network. It partners regional, national and international companies and government institutions at national and local level. Its mission is to make a direct contribution to industry and society through application-oriented research. The Fraunhofer IFF conducts its activities throughout the world, and has a market focus. It aims to develop holistic solutions. It can call upon an international research network of partner bodies in industry and the scientific community.

In research projects commissioned both by industry and by the public sector, the Robot Systems Business Unit of the Fraunhofer IFF develops new key components and technologies for future robot applications, and complete robot systems. The research and development activity of the Robot Systems Business Unit is focussed upon the following areas:

- Safe human-robot interaction
- Assistive robotics
- Service robots for inspection, cleaning and maintenance
- Robotics in production and in the life sciences (laboratories etc.)

Since 2010, the Fraunhofer IFF has conducted comprehensive studies of the physical and biomechanical aspects of human-robot collisions in order to formulate principles for the risks and limitations of workstations involving human-robot interaction. The emphasis currently lies upon determining the permissible stress variables in the event of a collision between a human being and a robot for the most diverse of impact scenarios and body regions. Based upon the results of the studies, functional and design requirements for the development of new safety technologies are defined, implemented and evaluated. These technologies include the development of tactile sensors, safe manipulator concepts, and control concepts for the safe braking and reaction behaviour of robots in the event of a collision.

2.1.2 Otto von Guericke University, Magdeburg – Institute of Forensic Medicine

Otto von Guericke University was founded In 1993 by the merging of the Technical University, the teacher-training college and the Medical Academy Magdeburg. It is the second-largest university in the state of Saxony-Anhalt after Martin Luther University in Halle. The Medical Academy Magdeburg was founded in 1954 by Professor Dr. med. habil. Hasso Essbach, who served as a pathologist. Forensic autopsies were initially performed at the Institute of Pathology.

Forensic Medicine became an institute in its own right in 1974, and still exists today. Besides teaching, the institute is responsible for the following activities:

- Forensic medicine
- Forensic odonto-stomatology
- Forensic genetics
- Clinical toxicology and alcohology

In its many years of activity in the sphere of forensic medicine, the Institute of Forensic Medicine has gathered comprehensive experience in the area of blunt, semi-sharp and sharp injuries on living human beings and corpses.

2.2 Project duration and supervision

The study ran from November 2012 to December 2013. During this period, it was supervised by a project support group consisting of representatives from the following institutions:

- Commission for Occupational Health and Safety and Standardization (KAN)
- Institute for Occupational Safety and Health of the German Social Accident Insurance (IFA)
- Deutsches Institut für Normung (DIN) e.V.
- German Federal Ministry of Labour and Social Affairs (BMAS)
- German Social Accident Insurance (DGUV)
- Woodworking and metalworking expert committee of the German Social Accident Insurance (BGHM)
- Südwestmetall
- Federal Institute for Occupational Safety and Health (BAuA)

Altogether, three project meetings were held between KAN and the project support group. Selected interim results were presented and discussed at these meetings, and additional secondary tasks presenting a useful supplement to the primary tasks of the study were also agreed. A list of all secondary tasks can be found in Section 2.3.

2.3 Tasks

The scope of the study included a number of mandatory tasks. From these, various work packages were created for organization of the project. Besides the mandatory tasks, the project support group defined further tasks in consultation with the consortium which supplemented the overall result of the study in a beneficial manner.

2.3.1 Mandatory tasks

Altogether, two areas of activity were to be addressed within the study:

1) Survey tasks

2) Development of proposals for how biomechanical stress limits could be graded and structured advantageously

The study's first area of activity encompassed a total of four sub-tasks; these were to be completed in the course of a literature survey. The following subject-matter was to be surveyed:

a) Biomechanical stress limits in the entire body of regulations
b) Biomechanical injury criteria in other subject areas
c) Medical and biomechanical injury criteria by means of which the injury severity category of "uninjured" (S0) and the categories S1 and S2 familiar from the area of machine guarding could be better specified
d) Applied injury severity scales and injury codes by means of which the injury severity categories could be classified

Since sub-tasks a) to c) overlap in their topics and content, they were merged to form the key terms of reference for the purpose of the survey work:

1) *Survey of biomechanical stress variables*

   What biomechanical stress variables and limits have been considered and where applicable used up to now in occupational safety and health and in other applications and subject areas that can be classified in their severity below the injury severity categories S1 and S2?

The focus of sub-task d) lay upon the surveying of injury scales and codes. This sub-task consequently differs in formal terms from the others. The terms of reference for the task were:

2) *Survey of injury severity scales and codes*

   What existing injury scales and codes are applied in practice that can be used to specify the severity categories So to S2?

Sections 4.2 and 4.3 present a breakdown of the results for this area of activity. A more detailed picture of the results can be gained by means of an Access database into which all titles describing relevant stress-strain relationships have been entered. Further information on this database can be found in Sections 3.2.5 and 7.2.

During completion of the second area of activity, proposals were developed for how the new So injury severity category could be defined and how biomechanical stress limits could be structured in the future for occupational safety and health purposes. The results are explained in Section 4.5.

2.3.2 Supplementary tasks

The following list summarizes the secondary tasks agreed by the project support group.

- Creation of a glossary of the specialist terminology used (see Section 7.4)
- Bounding of surveyed injury severity scales (see Section 4.3)
- Documentation of how the surveyed stress variables were measured and with what methods (see Section 4.2.1)

2.3.3 Work packages and outcomes

Table 1 shows the work packages completed during the study. The third column of the table indicates the number of the task to which the work package in question is assigned. The assignment of the work packages among the members of the consortium is shown in the last two columns. The work was assigned in consideration of the competencies of the two project partners, Fraunhofer IFF and the Institute for Forensic Medicine (IFR).

WP	Description	Task	IFF	IFR
1	Survey of regulations	1.a	x	
2	Survey of other areas of application	1.b	x	x
3	Consolidation of the results		x	x
4	Categorization of So	1.c	x	x
5	Survey of applied injury scales	1.d	x	x
6	Structuring of the stress limits	2	x	
7	Documentation		x	
8	Project management		x	

Table 1 Work packages and assignment of the tasks

During the study, a number of outcomes were produced which were made available to KAN following the study's completion. The outcomes were as follows:

- Concept paper on performance of a literature survey
- List of all databases consulted
- Index of search terms
- Search documentation
- CITAVI database containing all included titles (relevant hits)
- Access database containing all stress variables excerpted from relevant titles
- Data fact sheets (PDF format) on all relevant titles
- Concluding report, also containing:
    - Proposed definition for the So injury severity category
    - Proposed structure for stress variables
    - Index of search terms
    - Glossary

All listed outcomes were made available to KAN following completion of the study.

3 Survey and excerption of sources

The core task of the study comprised the performance of a literature survey for the purpose of compiling biomechanical stress limits that are used both in regulation and in other subject areas. The selection of the databases surveyed, the procedure for the survey, and the tools used for the purpose are described in the following sections. The excerption, the final step of the literature survey, is described in the last section of this chapter.

3.1 Survey of relevant information resources

Information resources refer to the databases and resources in which a survey was performed. For the literature surveys in this study, the databases were selected according to certain criteria as explained in the following sub-sections.

3.1.1 Circumscription of the information resources

The information resources were circumscribed substantially by the terms of reference as summarized in Section 2.2. Based upon the terms of reference, subject areas were defined which were to be covered by the information resources used. Table 2 summarizes the defined subject areas. The number of databases covering each subject area is also stated.

Subject area	Explanation	Number
Medicine	Covers all publications in the area of human medicine	90
Technology	Covers all publications in the areas of technology and engineering	65
Sport	Covers all publications in the area of sport	16
Traffic and safety	Covers all publications in the areas of road safety and accident research	8
Insurance	Covers all publications concerning health and accident insurance and related topics	2
Standards and technical rules	Covers all standards, technical rules, specifications and technical reports in the English-speaking and German-speaking world	20
Binding regulations	Covers all OSH legislation and related statutory provisions	30
(General)	These databases also cover other subject areas, but cover at least two of those stated here	79

Table 2. Circumscription of the databases by subject area (according to DBIS)

Besides the subject area, the database type also served as a selection criterion. Table 3 summarizes all database types considered for the survey.

Database types	Explanation	Number
Article database	Cross-disciplinary and/or subject area-specific articles from journals and similar series of documents (such as conference and congress reports); individual book chapters	68
Full-text database	Works of all kinds the full texts of which are accessible	82
Specialist bibliography	Works appearing independently and/or in conjunction with other works	90
Index of dissertations	References to dissertations within regional bibliographies	9
Reference work	Dictionaries, encyclopaedias, thesauruses, dictionaries of abbreviations	21
Bibliography of journals	Newspapers and journals catalogued in an index according to certain criteria	3
Portal	Collection of various databases, services, etc., presented in the form of a website, usually with a large number of links and serving as a starting-point for research of a particular topic	47
Factual database	Primary information structured with regard to its form and content, such as numerical data	12

Table 3. Circumscription of the databases by type (according to DBIS)

Besides the circumscription by subject area and type, general criteria were also applied as summarized in Table 4.

General criteria	Explanation
Availability	Besides freely accessible databases, databases were also used for which the Fraunhofer-Gesellschaft and Otto von Guericke University possessed a licence at the time of the study.
Language	Elements were considered during the survey only if they were in either English or German.
Publication period	Where the number of elements within the result set was very high, the information resources were circumscribed for a specific period.

Table 4. General circumscription of the databases

It should be noted that many databases can be assigned to multiple types and subject areas, or satisfy more than one of the general criteria. Only a small number of databases corresponded to only one type, one subject area or one criterion.

3.1.2 Selection of the information resources

Reviewed and continually maintained information resources are not generally available for use free of charge, but require purchase of a licence. Only in exceptional cases are high-quality information resources available for use free of charge. In addition to the relevant and freely accessible information resources, fee-based information resources were used for completion of the study for which the Fraunhofer-Gesellschaft, the Fraunhofer IFF and the library of Otto von Guericke University possessed licences at the time of the study. The number of discrete information resources over all subject areas exceeded 7,000 in total.

A total of 210 databases were selected from the available information resources as circumscribed in Section 3.1.1. The final selection also considered which text elements were searchable in addition to the elements provided as standard (author, title, place and year). These text elements are summarized in Table 5.

Indexed text elements	Explanation	Number
Abstract	The abstracts of the works listed are indexed for the search.	105
Full text	The full texts of the works listed are indexed for the search or can be called up.	73
Data	The listed data of a factual database are indexed.	18
Key words	The listed works of a database contain key words.	127

Table 5. Particular text elements that were indexed for searching within the databases

3.2 Literature survey

A number of tools were employed for performance of the searches. These tools are presented and explained in the following sub-sections. The methods employed for conducting and documentation of the searches within the databases are also described.

3.2.1 Key search terms

The (German) key search terms were defined based upon an analysis of the terms of reference. This analysis is described in Section 2.2. The key search terms served as a starting-point for the specification of alternative search terms (English translations and synonyms).

During selection of the key search terms, attention was paid to their suitability for use as key words covering a large proportion of the relevant hits. For this purpose, the terms were reviewed with the aid of selected reference works (dictionaries, encyclopaedias, thesauruses) in order for a suitable balance to be attained between their generic validity and their technical precision.

The key search terms are summarized in Table 6. They are sorted by relevance (relevance decreases with increasing number).

Relevance	Key search terms
1	Verletzung (injury)
2	Kraft (force)
3	Grenzwert (limit)
4	Biomechanik (biomechanics)
5	Unfall (accident)
6	Kontakt (contact)

Table 6. Key search terms employed

A detailed list of the key search terms used and their German and English synonyms can be found in the annex in Section 7.1.

3.2.2 Criteria for circumscription of the result set

The literature survey disregarded all works published prior to 1945, since their integrity would have been difficult to assess. This decision was taken by the consortium in close consultation with KAN and the project support group. In addition, it was not deemed expedient to consider published results obtained with use of the following test objects:

- Children (comprising test subjects before the age of maturity or corpses or body parts thereof)
- Sick test persons (comprising sick test subjects or corpses or body parts thereof)
- Animals (comprising living animals, animal cadavers or parts thereof)
- Dummies
- Models (FEM, multibody systems, etc.)

The scope of searches was circumscribed in accordance with the defined criteria primarily by the selective use of terms which were not permitted in the hits and were therefore defined as exclusion terms.

Where a result set contained a very high number of hits (>200) despite the use of exclusion terms, the constraint filters shown in Table 7 were employed.

Search filter	Explanation
Publication period	Constraint of the publication period of the works and titles to be searched
Author	Selection of specific authors of works and titles to be searched
Publishing house	Selection of specific publishing houses responsible for publishing the works and titles to be searched

Table 7. Further scope for refining the search by the use of search filters

3.2.3 Search tools

All relevant and irrelevant search terms were summarized in structured form in an index of search terms. A separate index of search terms was created for each database used. Each index was updated during and in response to the search until the number and quality of the hits satisfied the criteria. The index of search terms comprised three categories of terms:

- Key search terms (German)
- Alternative search terms (English translations and synonyms of the key search terms)
- Excluded search terms

Each term category describes a subset; these are combined to form the result set. Table 8 shows the structure of the index.

	Key search terms (German)			**Excluded search terms**
	Term.A	Term.B	Term.C	Term.X
Alternative search terms	Term.a1		Term.c1	Term.Y
	Term.a2			

Table 8. Structure of the index of search terms

The first row contains the (German) key search terms. Each column is assigned to no more and no fewer than one of these terms. The terms are listed according to their relevance (decreasing from left to right). The associated alternatives (English translations and synonyms) to each key search term are listed in the rows below. The final column contains the exclusion terms, i.e. the terms which must not be returned within the search result.

All alternative and excluded search terms were compiled in a table. This constitutes the overall search term index. This index contains all search terms used during searches covering all databases. The standard index of search terms was created from the terms with the greatest relevance in the overall index of search terms. The standard index of search terms served as the starting index for each initial search within a database.

As already stated, the result set is a combination of the sets formed from the listed search terms. The exclusion set (ES) was formed from the exclusion terms.

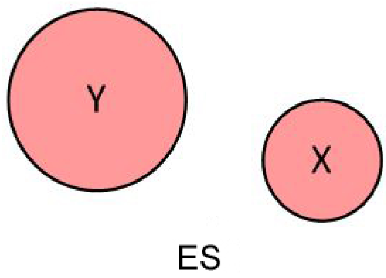

Figure 1. Exclusion set

The key search terms and/or their associated alternatives yielded one or more unions (U). The number of different unions corresponds here to the number of different key search terms.

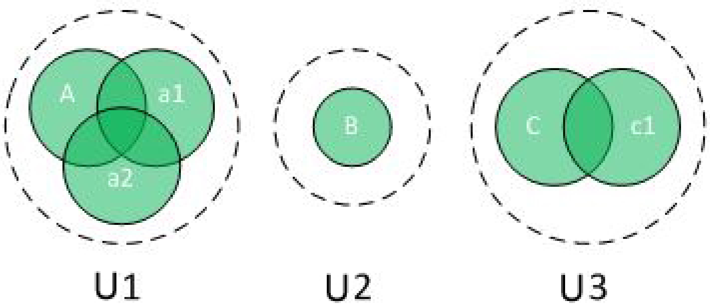

Figure 2. Unions

All unions (U) together then yielded an intersection (IS).

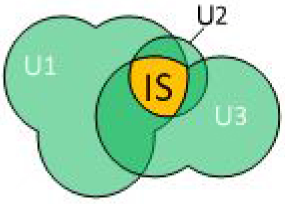

Figure 3. Intersection

In the final stage, the difference between the intersection (IS) and the exclusion set (ES) is formed, ultimately producing the desired result set (RS).

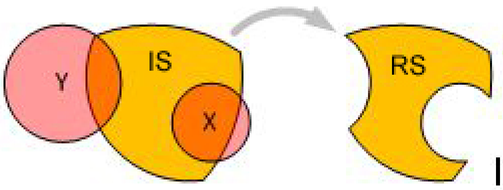

Figure4. Result set

Search command syntax and operators were used to produce syntactical search commands implementing the described set operations. Application of the search commands to a database produced the desired result set. Table 9 summarizes the search command syntax and operators used, which were supported by the majority of databases.

Search command syntax and operators	Explanation	Number
AND, OR, NOT	Logical expressions for circumscribing the result set	65*
( )	Bracketing for nesting the logical expressions	64*
""	Phrase search	65*
*****	Truncation	76*

Table 9. Search command syntax and operators (* these databases documented support of this search command syntax and these operators; the actual number of databases supporting them was higher)

The structured indexes of search terms and the search tools described here enabled numerous databases to be searched systematically and with efficient use of time.

3.2.4 Performance of searches

The standard index of search terms was always used for the first search in a database. This index was then adapted individually according to the result set. Any adapted search resulting in a substantial change to the result set was documented. Besides adaptations to the index of search terms, the search commands giving rise to a relevant result set were also documented, as were the number of hits and the date of the search.

The template for documentation of each search was written in Microsoft Excel, and employed a macro function which generated custom search commands from the index of search terms and the search command syntax shown in Table 9. This enabled complex search queries to be generated and adapted quickly and easily.

The result set was analysed and evaluated after each individual search during a search run. The purpose of this was to identify hits with little to no subject relevance and those with high to very high subject relevance. In both of these cases, new alternative and/or exclusion search terms were defined for addition to the overall index of search terms. The search command was then adjusted with the aid of the newly identified terms in order to constrain the result set suitably and thus to improve its quality. Terms that had not contributed to the result set were omitted. The entire process was then repeated until it was no longer possible to add any further terms to the index of search terms that further constrained the result set. The individual steps of this optimization process are shown in Figure 5.

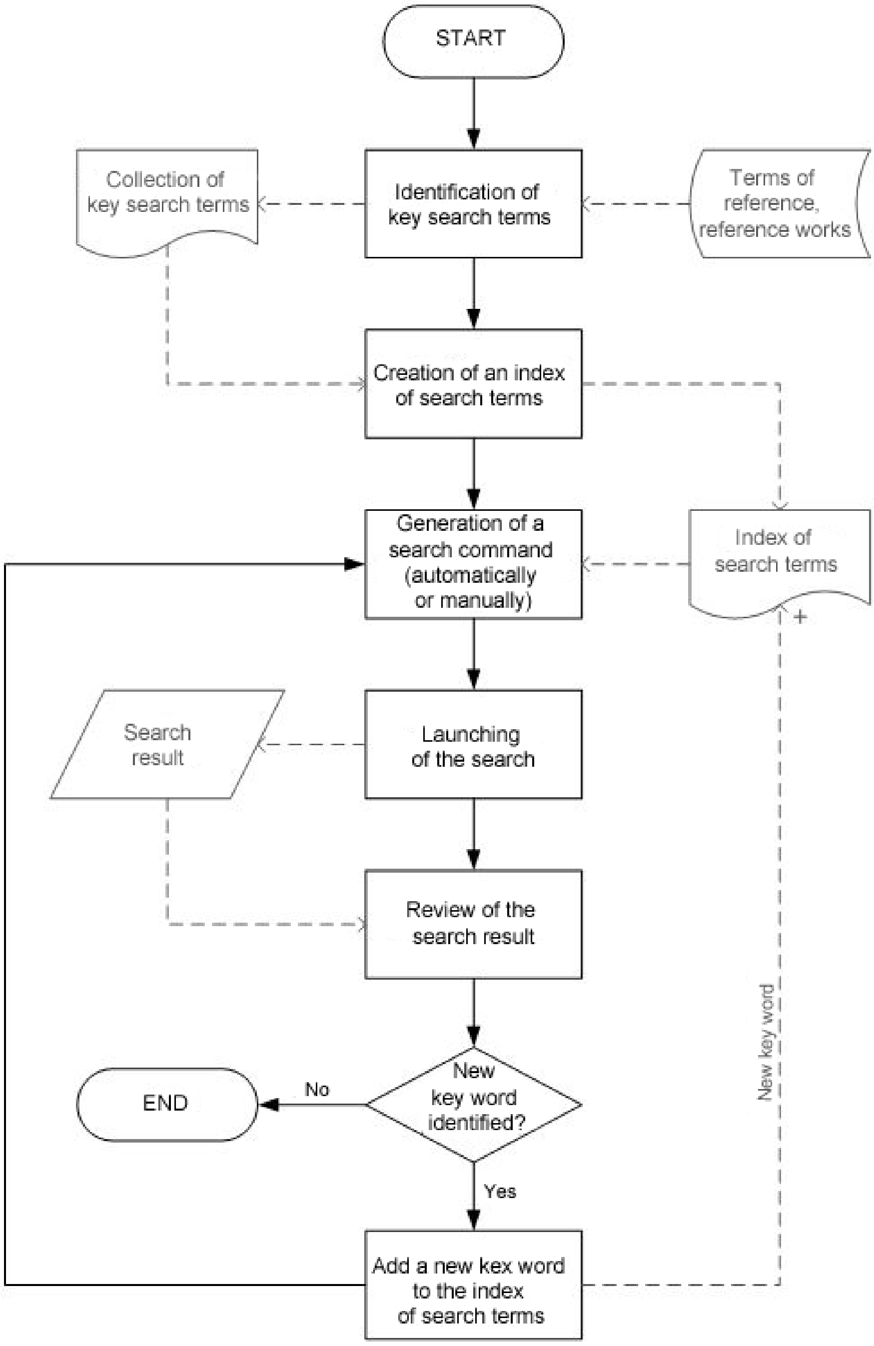

Figure 5. Flow chart of a search run

Where a very large result set could not be reduced by means of the procedure described here, up to three further key search terms were added to the index of search terms. If this also had no significant influence upon the size of the result set, the constraint filters shown in Table 7 were also used.

Where a result set yielded a very low number of search hits or none at all, the index of search terms was reduced. The procedure in this case was the opposite of that for circumscribing the result set.

3.2.5 Adoption of the search results

Once a result set could no longer be significantly adjusted, all hits contained within it were analysed and, where relevant, added to the overall result of the search. All titles classifiable as relevant in the context of the study were added to a central database of results. The CITAVI literature management program was employed for this purpose. CITAVI provides a structured environment for the storage and management of literature and similar media.

When a title was accepted, the researcher performed an initial ranking of its content. The content was ranked over five levels by application of the following criteria:

- The text contained key words from the index of key terms
- The text addressed at least one of the topics specified by the main tasks
- Specific biomechanical stress variables were stated

The individual ranking levels were indicated by stars. Table 10 explains the individual levels.

Stars	Explanation
★★★★★	Absolutely relevant
★★★★	Highly relevant
★★★	Relevant
★★	Less relevant
★	Barely relevant

Table 10. Five-level ranking of the search hits

3.2.6 Supplementation of the search results

Following completion of the search, a post-search survey was performed in order to enhance leverage of the available scope of results. The principle of "citation snowballing" was used for this purpose. This entailed further surveying of the literature references found in the highly ranked titles and, where these were found to be relevant, their inclusion in the overall result [6].

3.3 Inspection and excerption of the survey results

Inspection of a title refers to the review of its content for relevant information, which is subsequently retrieved during excerption and documented. Since over 1,000 titles were identified during the literature survey, it was necessary for them to be inspected in the (decreasing) order of their ranking. Owing to the high number of titles and the limited time available for completion of the project, it was not possible for all titles to be inspected.

3.3.1 Criteria for excerption of a title

During inspection of a title, it was first determined whether its content satisfied the formal criteria described in Section 3.2.2. If the criteria were not satisfied, the title was not considered further and was marked accordingly in the CITAVI database. If they were met, distinction was drawn according to further criteria:

- The title contains biomechanical stress variables which can be classified as shown in Table 11
- The target strain of the test lies in the region of the severity of injury specified by the terms of reference of the present study, i.e. collaborative robots (exceptions are for example all injuries from AIS2 upwards)
- The target strain of the test may conceivably fall within the terms of reference of the study (exceptions are therefore for example injuries such as whiplash, cruciate ligament injury, burns, etc.)
- The stress event in the test is described comprehensibly and the target strain is produced logically

#	Explanation
1	Entrapment/crushing
2	Impact
3	Fracture
4	Tension
5	Compression
6	Bending
7	Torsion
8	Triple-point bending
9	Acceleration

Table 11. Forms of stress considered

3.3.2 Structuring of the excerpts

A certain pattern was observed during inspection of the surveyed titles. Almost all titles described tests the structure and progression of which had a recurring form: the strain of a localization was brought about by a certain stress event on one or more test objects. A generated strain can therefore always be assigned to precisely one stress event. This assignment will be referred to below as the stress-strain relationship. In an experimental test, this relationship is always associated with a localization and a test object or group of test objects. Figure 6 shows a schematic diagram of the relationship between the individual elements of a stress test. As the figure shows, multiple localizations and/or test objects can be associated with a test independently of each other. This is particularly advantageous for tests in which multiple localizations or test objects were studied. The link between a stress-strain relationship on the one hand and a localization and one or more test objects on the other is however always unambiguous.

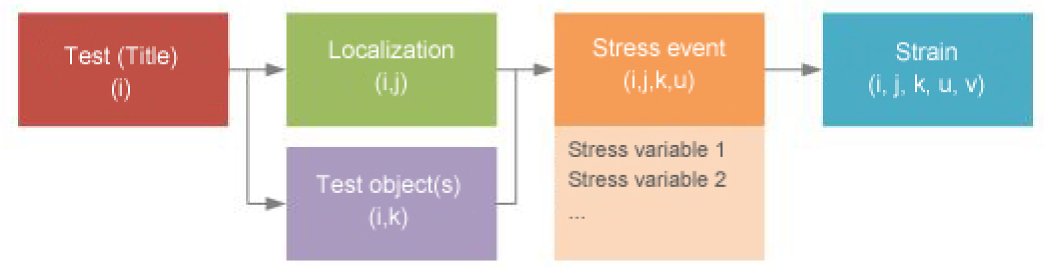

Figure 6. Relationship between the elements of an experimental test

3.3.3 Documentation of the excerpts

Based upon the pattern shown in Figure 6, the Institute for Occupational Safety and Health (IFA) developed a database by means of which the results of tests of this type can be documented comprehensibly [7]. For the purposes of the present study, an Access database was developed based upon the IFA database in which excerpted data can be saved in a user-friendly input dialog. The input dialog is shown in Figure 7.

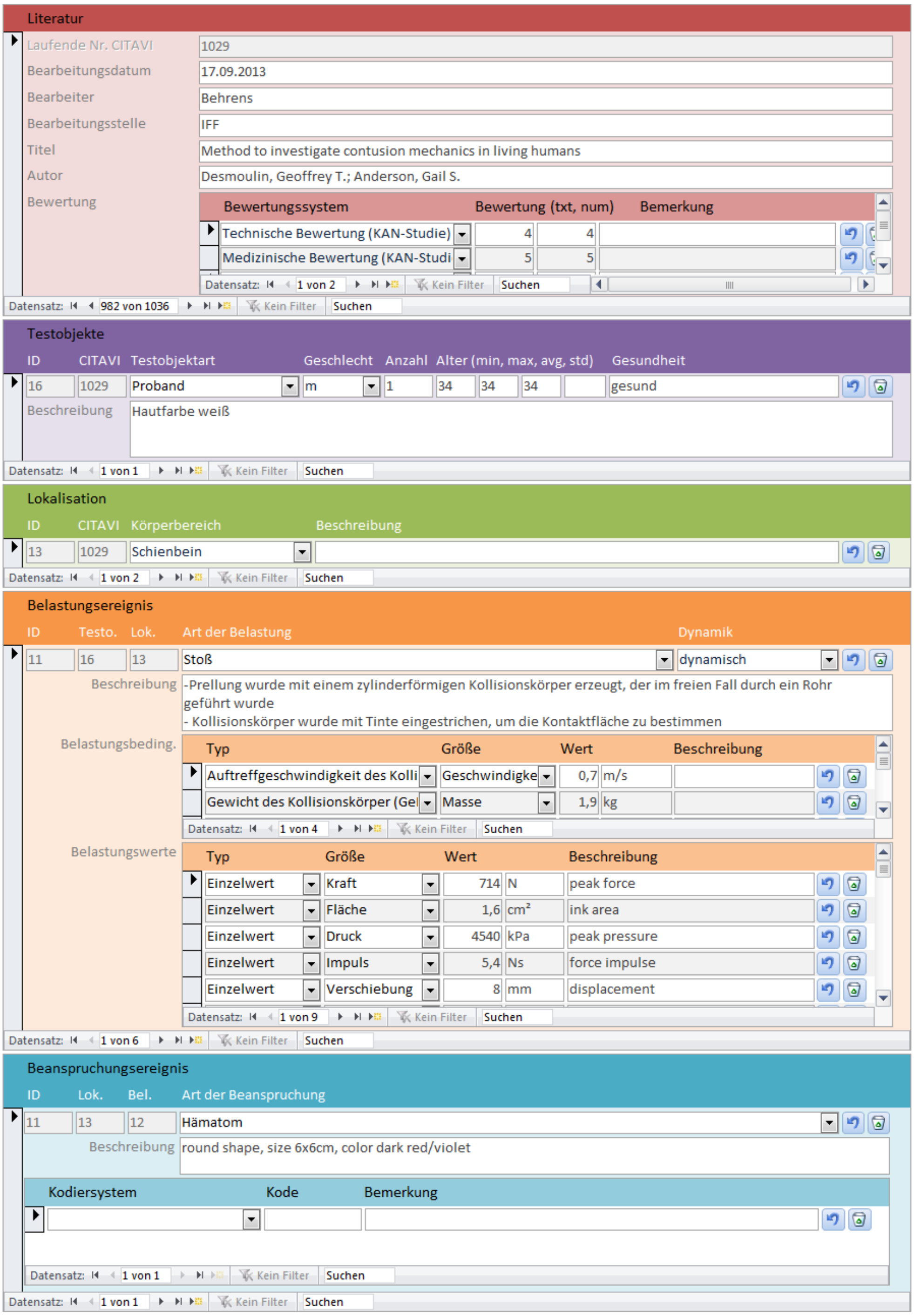

Figure 7. Dialog in the Access database for input of excerpted data

Following completion of inspection and excerption, each inspected title in the CITAVI database was assigned to a category in Table 2, making the topic addressed by the title identifiable at a later stage when the database is accessed.

3.3.4 Ranking of the excerpted titles

All excerpted titles of scientific publications were ranked with regard to two aspects:

1) Quality of the test arrangement and of the measurement procedure (technical ranking)

2) Quality of the medical description and of the examination of the strain (medical ranking)

Altogether, three criteria were defined for each aspect. Each of these criteria could be ranked differently. The rank given to a criterion serves here as a dimension of the quality of the test with regard to the aspect concerned. The sum of the discrete values for an aspect had a maximum level of five. Table 12 summarizes and explains the criteria for the technical ranking; Table 13 those for the medical ranking. It should be noted that standards and other titles from the regulatory sphere were excluded from this ranking, as they require no justification.

Criterion	Value	Explanation
Test arrangement	0	The test arrangement is not described or is unsuitable for the studies.
	1	The test arrangement is suitable for performance of the studies, but its description is not conclusive.
	2	The test arrangement is suitable for performance of the studies and is conclusive.
Performance of testing	0	No steps for the performance of testing are described, or major errors in the performance of testing are suspected.
	1	The performance of testing is not fully documented.
	2	Performance of testing can be fully reconstructed from the description.
Interpretation	0	Interpretation of the measured data is not described.
	1	Interpretation of the measured data is documented.

Table 12. Criteria for technical ranking of an experimental test

Criterion	Value	Explanation
Approach	0	The approach of the study is not described, or is not suitable for attainment of the study objective.
	1	The approach is suitable; some aspects are however not ideal (for example: average age of the test objects too high).
	2	The approach is suitable for attainment of the study objective.
Strain	0	The injury is not described.
	1	The description of the injury is incomplete.
	2	The injury is fully described.
Localization	0	Localization is described unclearly or not at all.
	1	Localization is described clearly.

Table 13. Criteria for medical ranking of an experimental test

4 Overall result of the study

The results of the study are compiled in the following sections with indication of their scale and quality. In addition, the discrete results from the selected subject areas are examined more closely and ranked in terms of their relevance to the study. Proposals are also made in this section for defining the So injury severity category and for structuring of stress limits for future occupational safety and health activity. Finally, this chapter summarizes and discusses the progress and results of the study.

4.1 Result in figures

The **245** databases surveyed were selected from a total of over **7,000** information resources. Altogether, **1,036** titles were added to the CITAVI database. Figure 8 shows the breakdown of the 1,036 titles by rank. The titles were ranked in accordance with the ranking system described in Section 3.2.5. As can be seen, 33 titles were not ranked, since their subject-matter did not fall within the scope of the study. These titles include literature concerning the performance of a systematic survey, for example.

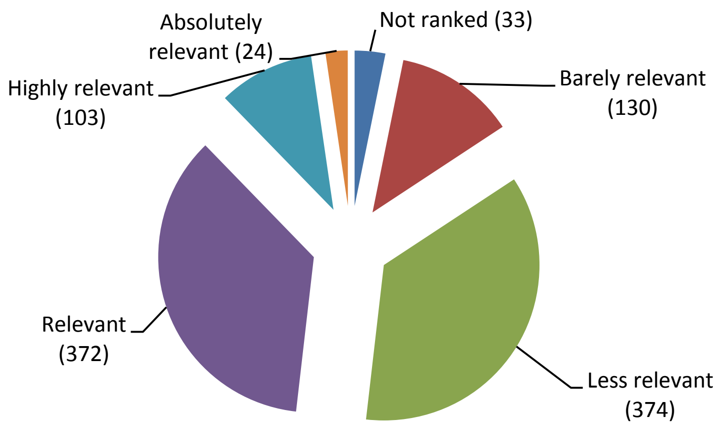

Figure 8. Breakdown of the surveyed titles by rank

The titles contained in the CITAVI database were obtained and inspected systematically, beginning with the more highly ranked entries. Figure 9 shows the numbers of the inspected titles by status. As shown in the figure, a total of **407** titles were inspected, of which 250 were found to be unsuitable. In total, data from **100** literature sources were input into the Access database, which has already been referred to in Section 3.3.3. Titles with the status of "Other" are sources from which data could not be retrieved directly, such as literature on injury severity scales or secondary sources used for citation snowballing (refer also to Section 3.2.6). Titles were marked "Inaccessible" either when they could not be obtained owing to lack of time or for other reasons, or when the cost of their procurement was excessive in relation to their ranked relevance. Titles which are also found in the IFA database [7] (a total of 23) and were not accessible were marked separately. The possibility thus exists for the titles concerned and the data contained in them to be accessed in future directly through the IFA database. In total, 146 available titles were not inspected owing to insufficient time being available. It should however be noted that the relevance of these titles was considered low (lower than three stars, see also Table 10).

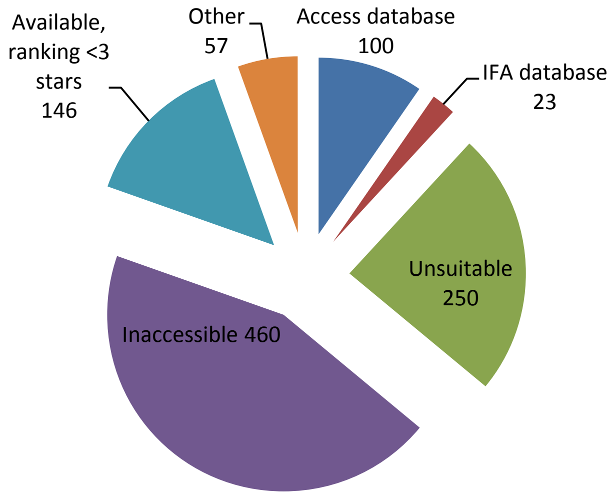

Figure 9. Status of the surveyed titles following inspection

The assignment of the 407 inspected titles to the subject areas stated in Table 2 is shown in Figure 10. A similar distribution is also observed for the titles input into the Access database, as can be seen in Figure 11.

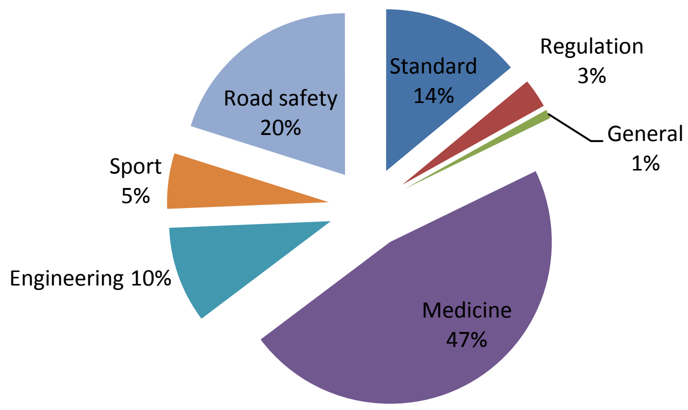

Figure 10. Breakdown of the inspected titles, by subject area

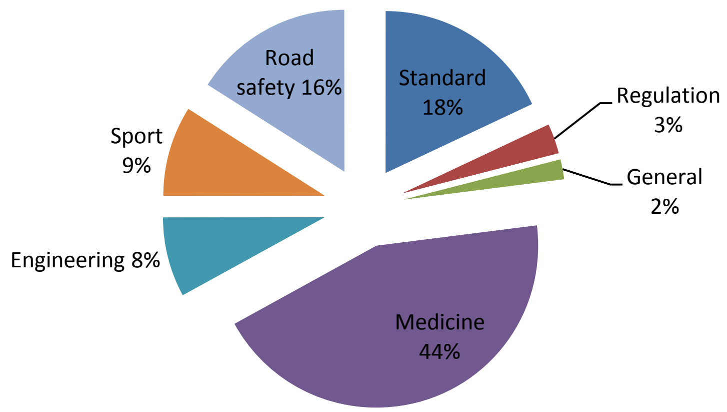

Figure 11. Breakdown of the titles in the Access database, by subject area

The results were consolidated in a concluding workshop held by the project contractors. The titles input into the Access database were ranked again at this point according to their relevance to the study. This ranking differs from that described in Section 3.3.4, which relates to technical and medical aspects. The distinguishing characteristics of the concluding ranking and their significance are summarized in Table 14.

Level	Explanation	Significance
1	Absolutely relevant	Standards and documents from the regulatory sphere and projects in which studies were performed involving test subjects
2	Relevant	Titles describing tests on post-mortal test objects, performed under realistic conditions (in the context of the study)
3	Less relevant	Titles describing tests on parts of post-mortal test objects, performed under realistic conditions (in the context of the study)
4	Of doubtful relevance	Titles describing tests performed under unrealistic conditions
0	Secondary sources	Titles referring to other studies and which could not be ranked owing to a lack of information on the test conditions

Table 14. Concluding ranking of the included titles with regard to their relevance to the study

Figure 12 shows the distribution by rank of the final overall result of the study.

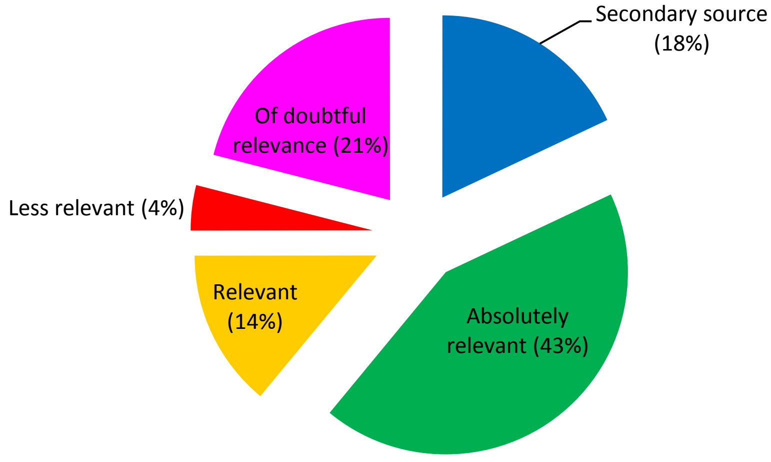

Figure 12. Breakdown of the titles in the Access database by rank (final overall result)

Somewhat over 550 stress-strain relationships were accepted from the 100 titles in the Access database. Approximately 1,500 measured stress values (measurable physical variables) are assigned to these relationships. The 560 stress-strain relationships are in turn combinations of approximately 200 different test objects and approximately 250 localizations.

4.2 Orienting comments on the relevant sources of the results

The figures presented in the above section show that despite the very large number of surveyed titles, very few of them contained relevant data. This section discusses the main reasons why the majority of the inspected titles were not suitable for inclusion in the Access database. The individual subject areas will be considered separately for this purpose.

Consolidated observations regarding the results from the main categories are presented briefly in the following sub-sections:

- Scientific literature
- Standardization and regulation
- Portals
- Secondary sources

4.2.1 Scientific literature

Scientific publications constitute the majority of titles surveyed for the purpose of this study. The projects differ, in some cases strongly, in their study content, their objectives, and the subject areas in which they were performed. The findings of the survey in individual subject areas will be considered briefly below.

Sport – The titles surveyed in the subject area of sport were for the most part unsuitable for excerption, since they primarily addressed biomechanical stresses arising during physical training for certain sporting disciplines. These titles focus for example upon injuries caused by sustained stresses, the consequences of fatigue, or unsuitable sporting equipment.

Road safety – Besides crash tests (employing dummies, animal cadavers and human corpses), the focus lies primarily upon the retrospective evaluation of injury processes occurring during accidents. The results of such studies were not input into the Access database. Despite the limited suitability of crash tests, results of stress tests in this subject area involving human corpses were nevertheless included in the overall result. It should however be noted that owing to the high stresses (high velocities, high masses), the limits determined constitute a measure for the probability of survival by the occupants of a vehicle. The stress limits for absolute physical integrity of the occupants in the event of a crash were not studied in any of the titles.

Insurance – The titles in the subject area of insurance are all primarily concerned with the reconstruction of accidents, for example for the purpose of detecting insurance fraud. The purpose of studies in this subject area is to determine not what measurable physical variable (stress) gave rise to a strain, but whether the strain can be linked to the stated event as a consequence of the stress. The titles surveyed in this subject area were therefore unsuitable for the purposes of the present study.

Medicine – Medical publications generally contained only measured values and not limits, since the number of test objects (human corpses), frequently being low, did not enable limits to be defined. For this reason, these publications describe only the result of a specific stress, without drawing conclusions from it regarding threshold levels. Many titles were also found to study only the target strain, without examining consequential strain in any greater detail. For example, where fracture forces were examined in dynamic collision tests, the focus lay solely upon the fracture of structural tissue; damage to soft tissue was not examined in more detail.

Technology – In the titles classified within the general subject area of technology, the technical elements (structure, measurement methods, etc.) were adequately described in the majority of studies. By contrast, the documentation of the medical aspects exhibited significant deficits in areas such as localization and injury patterns. A failure to use specialist terminology and questionable approaches were among the deficits most frequently noted.

Studies involving human corpses were performed primarily in the areas of road safety, medicine and technology. The survey revealed that the average age of the human corpses used was very often $over\ 65$. In addition, only small numbers of test objects were generally available for studies; the statistical relevance of the study results is therefore generally low. Furthermore, no verified conclusions were known at the time of the study concerning the suitability of human corpses for the determining of biomechanical stress limits and the extent to which the mechanical properties of corpses differ from those of living persons. The use of human body parts for certain stress scenarios must also be called into question. In pendulum and drop tests – the tests most frequently used – in particular, reciprocal influences with other body parts are always present. The measurement equipment employed differed widely in its quality between the titles as a whole. Only a small number of titles documented error-free use of the measurement equipment.

4.2.2 Standardization and regulation

Since no obligation exists for the information originating from the area of standardization and regulation to be substantiated, surveys of corresponding sources were not possible. The observations upon which the selected limits were based are documented in very few standards. Table 15 lists all the standards in which actual biomechanical limits were found. The compilation of the values showed that certain limits occur repeatedly, such as $150\ N$ for the maximum contact force and $4\ J$ for the maximum permissible energy for a moving part on a machine. It should be noted that these values are examples which must be considered strictly in the context of the standard concerned, and not as having generic validity.

Number	Title
EN 1870-14:2012-06	Safety of woodworking machines – Circular sawing machines – Part 14: Vertical panel sawing machines
EN 1870-18:2013-08	Safety of woodworking machines – Circular sawing machines – Part 18: Dimension saws
E DIN EN 1870-19:2011-12	Safety of woodworking machines – Circular sawing machines – Part 19: Circular saw benches (with and without sliding table) and building site saws
EN 60335-2-79:2010-01	Household and similar electrical appliances – Part 2-79: Particular requirements for high pressure cleaners and steam cleaners (IEC 61J/380/CD:2010)
E DIN EN 60335-2-107:2010-04	Household and similar electrical appliances – Part 2-107: Particular requirements for robotic lawnmowers (IEC 116/25/CDV:2009)
EN 931:2010-07	Footwear manufacturing machines – Lasting machines – Safety requirements
EN 528:2009-02	Rail dependent storage and retrieval equipment – Safety requirements
EN 13814:2005-06	Fairground and amusement park machinery and structures – Safety
EN 1525:1997-12	Safety of industrial trucks – Driverless trucks and their systems
EN ISO 13856-2:2013-08	Safety of machinery – Pressure-sensitive protective devices – Part 2: General principles for the design and testing of pressure-sensitive edges and pressure-sensitive bars

EN ISO 13856-3:2012-03	Safety of machinery – Pressure-sensitive protective devices – Part 3: General principles for design and testing of pressure-sensitive bumpers, plates, wires and similar devices
EN 397:2013-04	Industrial safety helmets
EN 812:2012-04	Industrial bump caps
PD CEN/TR 16148:2011-06	Head and neck impact, burn and noise injury criteria. A Guide for CEN helmet standards committees
E DIN EN 415-10:2011-08	Safety of packaging machines – Part 10: General requirements
EN 12453:2001-02	Industrial, commercial and garage doors and gates – Safety in use of power operated doors – Requirements
E DIN EN ISO 14120:2013:09	Safety of machinery – Guards – General requirements for the design and construction of fixed and movable guards
IEC 62368:2010-01	Audio/video, information and communication technology equipment – Safety requirements
EN 415-8:2011-06	Safety of packaging machines – Part 8: Strapping machines
CSA B44-00	The Safety Code for Elevators

Table 15. List of included standards

Specifications were also found for the conducting of special test procedures in the automotive sector. The limits specified by the *Economic Commission for Europe* (ECE) and the *Federal Motor Vehicle Safety Standards* (FMVSS) were included within the overall result. Worthy of mention at this point are the following organizations, which have published similar test methods for determining the protection offered to passengers of vehicles:

- Global Technical Regulations (GTR)
- China Compulsory Certification (CCC)
- TRIAS, the Japanese equivalent of the ECE
- Federal Aviation Regulations (FAR)
- Joint Aviation Authorities of Europe (JAR)

The corresponding documents were not accessible at the time of the study, or proved unsuitable.

4.2.3 Portals

Portals offer the facility for information on a topic to be called up in a structured form, and provide access to further information. Two portals were identified by the literature survey as having content highly relevant to the subject of the study:

TIM – The Wiki for Trauma Biomechanics Experts – This wiki is an integral component of the Research Network for Trauma Biomechanics. It serves as a consolidated knowledge resource and provides reliable management of scientific findings relating to the incidence of injuries. The core objective of the Research Network for Trauma Biomechanics is that of enhancing communication, publicity and co-ordination of research projects in the area of trauma biomechanics, across disciplines and both in Germany and internationally. The founding members include the German Federal Highway Research Institute, Regensburg University, Ludwig Maximilian University in Munich, and the PDB Partnership for Dummy Technology and Biomechanics founded by Audi, BMW, Mercedes, Porsche and Volkswagen.

The wiki can be accessed at:

https://wiki.traumabiomechanics.net

It was last accessed for the purpose of the study on 17 November 2013. Use of the wiki requires registration on the following page:

http://www.traumabiomechanik.net/tim-wiki/

Trauma scores – A comprehensive collection of applied classifications and scores in the area of traumatology and orthopaedics can be found at:

http://traumascores.com/

It was last accessed for the purpose of the study on 17 November 2013. Besides a range of trauma scores, the website also contains contextual content useful for additional classifications and better comprehension. The website facilitates searches for classifications and scores in order to make diagnoses, therapies and prognoses more comparable.

It should be noted that this portal also contains classifications and scores for diseases that are not caused by biomechanical stresses (such as osteoporosis).

4.2.4 Secondary sources

Secondary sources are titles (reviews and surveys) compiling results from other titles. In the majority of cases, it was not possible to obtain the titles from which the results were obtained. It was therefore possible only in exceptional cases to include secondary sources in the Access databases when important information was stated on the test conditions associated with the stress-strain relationships. All secondary sources that could not be included in the Access database and for which as a result no data fact sheets exist are marked with the status "secondary source" in the CITAVI database. The secondary sources include the concluding reports of the studies that have already been presented in Section 1.2.

4.3 Injury severity scales and injury codes

The search for relevant injury severity scales, scores and injury codes was very difficult, owing to their wide diversity combined with the almost complete impossibility of verifying their adoption. Whether scales, scores and codes had been recognized and widely adopted could be determined only in a small number of cases. Many scales and scores were also found not to cover the area of minor injuries, which constituted the focus of the present study.

The scales and scores with the widest acceptance and adoption were seen to be those in the area of vehicle safety. A compilation of the most widely established scales and scores can be found in [8] and [9]. Attention is also drawn at this point to a very detailed study of risk assessments [10]. This may be helpful for the defining of risks.

4.3.1 Injury severity scales

The most frequently used scale for the classification of injuries was, as expected, the Abbreviated Injury Scale (AIS). Other scales were found only rarely and in isolated titles, and are in any case not worthy of further consideration, since they failed to satisfy the criteria in the following respects:

- No measurable adoption (the scale concerned was used in only one publication)
- The severities of the classified injuries lay above the AIS range for "minor injuries" and therefore fall outside the scope of this study
- The scales were conceived for particular stress-strain relationships that do not fall within the scope of the study

One exception to this is the Minor Injury Severity Scale (MISS). This injury scale was developed in order to classify indicators of superficial injuries among children. Children's daycare facilities and schools were considered as possible areas of use of the scale. The scale has a numerical range of 1 to 7, each value being assigned to an injury pattern listed in Figure 13. The injuries considered are assigned to a severity category according to their intensity. These categories include a category for minor injuries, making MISS well suited to use in the context of the new injury severity category of S0. It could not be ascertained during the study whether MISS is actually in use [11].

Categories Included in the Minor Injury Severity Scale (MISS)

Animal scratch/Bite	Firearm/Bow	Puncture/Splinter
Bruise/Bump	Floor/Rug burn	Scrape
Burn	Gymnastics	Stings
Choke/Drown	Joint/Bone/Muscle	Testicle impact
Crushing injuries	Loss of consciousness	Tooth injuries
Cut	Nosebleeds	Torn finger/Toenails
Electricity	Paper cut	
Eye	Poison	

Figure 13. Injuries categorized by the Minor Injury Severity Scale

The authors question in principle whether an injury severity scale for minor injuries is useful for the injury severity category of S0, since the scope of "minor injuries" can be constrained accurately to a small number of superficial injuries. They do not recommend that AIS be used in order to define S0, since the lowest value (AIS1) extends to breakage of a rib, which has a lethality of 0.7%. AIS is however certainly suitable for the existing injury severity categories of S1 and S2.

4.3.2 Scores

In the course of the literature survey, the following scores were identified the approaches of which were suitable if needed for the ranking of injuries in an occupational safety and health context:

Mayo Wrist Score – This score was developed for the ranking of injuries to the wrist bone. The ranking is based upon findings in the categories of pain, functional status, range of motion, and grip strength. The findings are specified and correspond to a numerical value. The final result is formed by summation of the values of the finding, and permits objective estimation of a patient's condition. [12]

Score of the OAK group (orthopaedic working group knee) of the Swiss Society of Orthopaedics and Traumatology – This score is an established instrument for assessing the functionality of the knee joint. The OAK score, in which 40% of the total number of points is assigned to the "stability" parameter alone, is not a purely anamnestic or subjective study instrument. The distribution between subjective and objective criteria is stated as 25% vs. 75% according to assignment of the points. Besides stability, the score takes account of aspects such as the range of motion, difference between circumferences, swelling and assessment of function. The subjective assessment relates to frequency of pain, activity level and sense of instability. [13]

Weber score – This score is generally applicable to the ankle joint. It is recommended by the German Society for Orthopaedics and Traumatology, the German association of orthopaedic physicians, and also in the guiding principles for orthopaedics. Pain, function, stability, and the results of radiological imaging are considered with regard to correct anatomy and osteoarthritis. [14]

It should be considered that the scores stated here are intended only for a particular part of the body and are adapted to specific injuries and diseases. Nevertheless, the scores presented here demonstrate that it is relevant to consider the consequences of strain resulting from a stress event. Besides pain and actual symptoms of injury, criteria such as the activity level and well-being are also considered. These aspects could possibly also be considered for mechanical risk assessment in occupational safety and health, which up to now has considered only the direct strain such as pain and/or injury.

4.3.3 Injury codes

The study identified only two coding systems which were used to classify injuries in multiple titles:

- AO classification of soft tissue injuries [15]
- International Classification of Diseases (ICD), Chapter XIX, "Injury, poisoning and certain other consequences of external causes" [16]

Both coding systems can be applied without restriction to all human body regions. Compared to the ICD, the AO classification is strongly focussed upon fractures and secondary injuries, as a result of which it cannot be used for all injuries involving blunt force. Conversely, Chapter XIX of the ICD covers substantially more injury patterns. Preference should therefore be given to the ICD over the AO classification.

Owing to its notable completeness and its adoption worldwide, the ICD (currently available in its tenth revised version) is recommended for the circumscription of injuries during mechanical risk assessments conducted for occupational safety and health purposes.

4.4 Proposed definition for the S0 injury severity category

A proposed definition was drawn up for an S0 injury severity category describing a certain severity of injury as the boundary to the next category, S1. Besides the definition, a concept was developed for the integration of S0 into the existing structure of injury severity categories.

4.4.1 Proposed definition

"The S0 injury severity category covers solely superficial injuries that heal without consequences even without medical treatment. Puncturing of the epidermis is not permissible and is therefore excluded from this category. For example, a light contusion of the forearm without injury to the epidermis would be classified as S0, whereas a graze to the heel of the hand would constitute S1."

Actual injuries are assigned to their respective categories based upon ICD-10 GM (see Tables, pp. 69 ff).

4.4.2 Information on the proposed definition

Note the following during interpretation of the proposed definition:

- Any injury that heals without consequences even without medical treatment will nevertheless heal more quickly if treated appropriately; the definition does not exclude the need for a minor injury to be treated.
- Pain is a firm component of S0. Use of the pain intensity for the definition of S0 is however not recommended: the sense of pain is highly subjective and is not therefore easily quantified.
- All injuries not listed in Section 7.3 must be assigned to Categories S1 and/or S2.
- The S0 injury severity category covers the range from uninjured (possibly with the onset of pain) up to the threshold of minor injuries (possibly in accordance with the definition of AIS 1, "minor injury").

4.4.3 Classification

The S0 injury severity category proposed here is treated as a range in the same way as the established categories of S1 and S2. S0 is not therefore a threshold marking the point of transition between two injury ranges; rather, the transition between ranges is defined by firm limits that correspond to specific strains/injury patterns.

The new S0 injury severity category must be placed below the existing category of S1. The transition from S0 to S1 is defined by the onset of minor injuries, as summarized in the tables on pp. 69. Consequently, only very slight injuries are permitted within the So range. The definition and assignment from AIS 1 may be used for the classification of slight injuries [17].

A further range, which is to be located below So, is a harmless range (H). The transition from the harmless range H to the So range could be defined by the limits corresponding to the pain threshold (transition from a feeling of pressure to one of slight pain). All stresses lying below the limits of H would then be classified in the mechanical risk assessment as harmless, as a result of which special protective measures would not necessarily be required.

The positioning of the new So injury severity category and of the H harmless range in relation to the existing categories of S1 and S2 is shown in Figure 14.

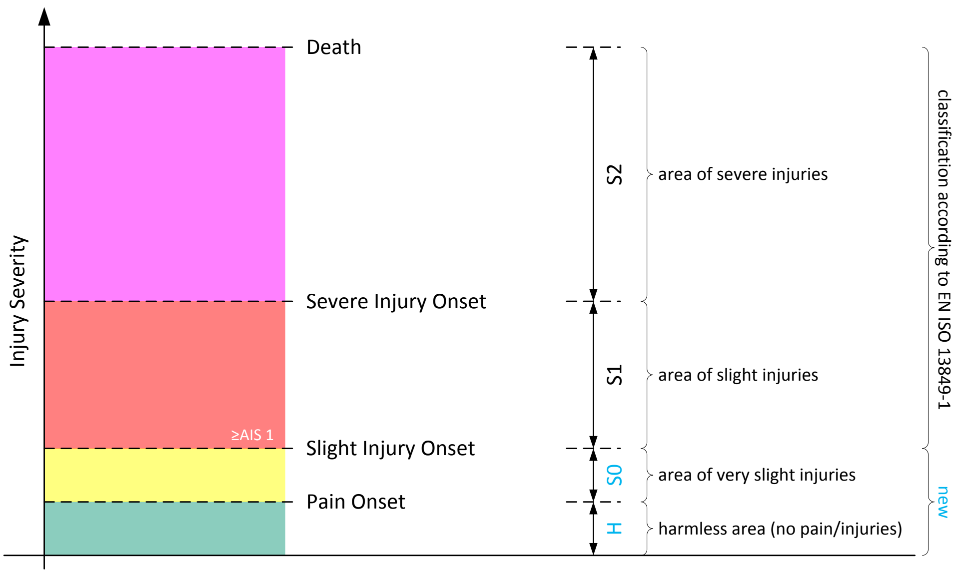

Figure 14. Integration of the So injury severity category and of the H harmless range within the structure of the existing categories

4.5 Proposal for the structuring of stress limits in modern occupational safety and health activity

It was not possible in the course of the study to determine physical variables which are exclusive in influencing a specific strain. The only exception is the variable of force, which was used uniformly in all relevant titles to quantify the incidence of fractures. For certain strains, such as contusions, multiple stress variables were stated in a number of titles without a specific variable being identifiable as having the clearest influence upon the strain. The majority of the inspected titles considered only one stress variable, without studying the actual level of its influence.

Owing to this situation, it is not possible to state physical variables by means of which biomechanical stresses can be circumscribed generically and logically for all conceivable strains and localizations. It was observed for discrete stress events in particular that the crucial stress variables and their combinations are not known for a large number of strains.

Even though it is not possible for specific stress variables to be stated, it is known that their combination with a geometric quantity and a time can have a substantial influence upon a certain strain. It is known for example from forensic medicine that the severity of a haematoma is dependent upon the energy absorbed within a certain area and time [18]. Equally, it is known from pain threshold measurements that the maximum contact force in conjunction with the peak (pressure) value of the surface pressure between the skin and the contact body is relevant for the quasi-static stress case [19]. Conversely, only a force value need be considered in order for maximum closing forces on automatic doors to be determined (assuming standardized closing edges) [20]. In a study of the maximum impact stress upon the feet in a head-on crash between cars, the concept of a "coupling criterion" was introduced for stress-strain relationships dependent upon more than one variable or parameter [21].

As the representation shows, the incidence and/or form of a strain may be influenced by up to three different variables and parameters. For the structured presentation of biomechanical stress variables, a form of representation was developed capable of expressing up to three influencing variables. The structure of this representation is based upon EN 62368 [22], in which stress variables are presented in a similar form.

The example representation in Figure 15 can be used for a total of three influencing variables. It consists of an abscissa (x axis) and several ordinates (y axes). The example below shows the use a geometric variable on the abscissa. Conversely, each ordinate is assigned to a different duration. In the plane created by the abscissa and the ordinates, coloured regions mark different strain thresholds (such as pain or a minor injury). The anticipated strain can be read off in the co-ordinate system from the available values of the influencing variables and parameters. The applicable ordinate is that the reference value (in this case a duration) of which is satisfied by the variables.

In the example shown in Figure 15, the influencing variables are shown for a transient collision on a certain body region:

- E_{ab} Absorbed collision force
- A Contact surface area
- T Duration of the force pulse

In order for the stress event to be classified, the applicable ordinate is determined from the measured pulse duration. The applicable ordinate is the one with a time value lying at the end of the time window in which the measured pulse duration lies. If for example a pulse duration $T\ of\ T^*$ was measured, the ordinate for which $T = T_2$ is the applicable ordinate when $T_2 < T^* \leq T_1$. The absorbed energy (which can be determined by measurement of the contact force and penetration) and contact surface area then yield the associated strain.

Figure 16 shows the representation for two influencing variables with reference to an example of the pain threshold measurement described above. Figure 17 shows the representation with reference to crush forces on automatically closing doors. In principle, any appropriate stress variables can be used within the representation of the stress-strain relationship, which can be adapted individually to each application scenario.

It should be noted that each representation of a stress-strain relationship always applies to a specific body region. In addition, the representation must use percentiles stating the percentages of the target population within and outside the limits of the range. For subdivision of the human body, reference is made to the IFA, which has developed and published a well-structured body atlas of main and specific regions of the human body [23].

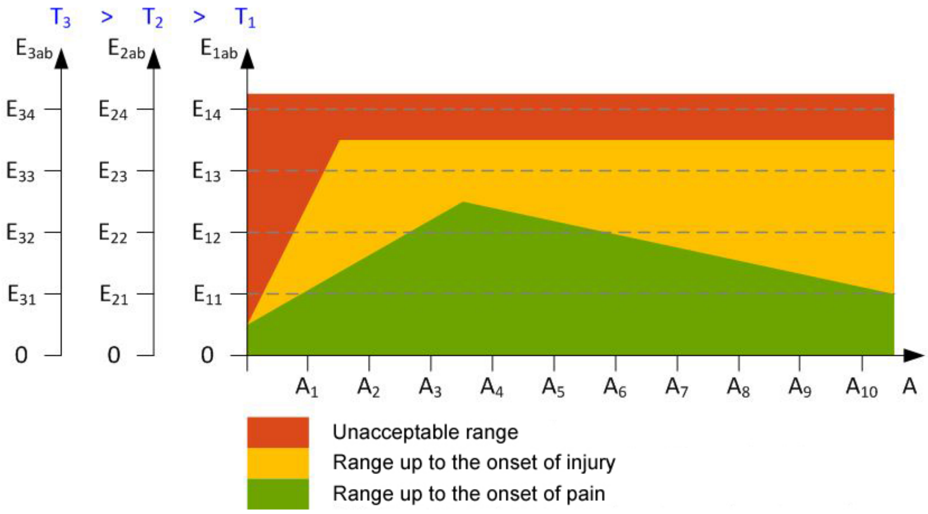

Figure 15. Example representation of the stress-strain relationship for three influencing variables (example here: contusions)

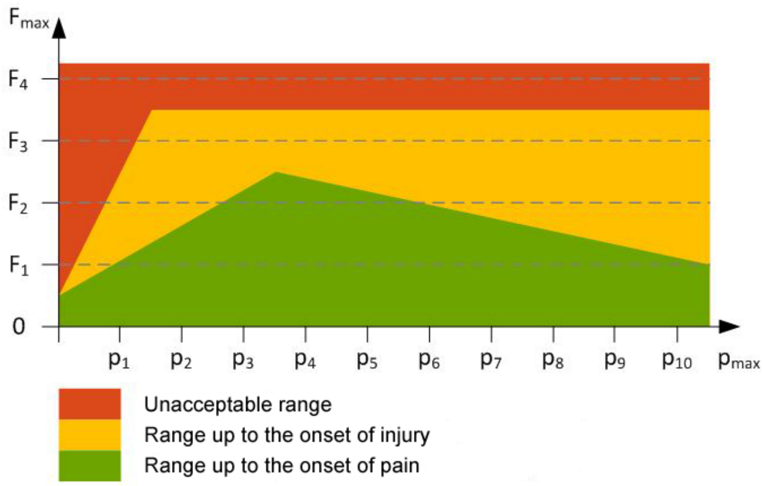

Figure 16. Example representation of the stress-strain relationship for two influencing variables (example here: pain thresholds)

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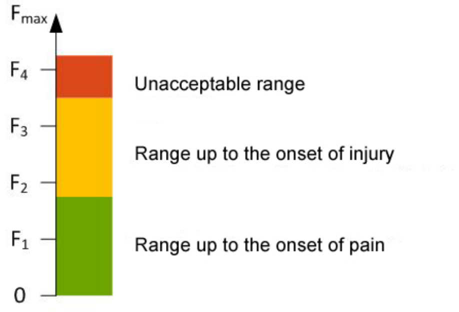

Figure 17. Example representation of the stress-strain relationship for one influencing variable (example here: crush forces on automatically closing doors)

4.6 Discussion

During the literature survey, use could not be made of the databases of the following bodies, for which charges apply:

- Society of Automotive Engineers (SAE)
- Stapp Car Crash Conference
- Transportation Research Board (TRB)

Numerous hits classified as relevant were present solely in one or other of these databases. Since neither the Fraunhofer-Gesellschaft nor Otto von Guericke University has access to them, the titles concerned could not be inspected, and are therefore marked "inaccessible" in the CITAVI database. The authors urgently recommend that these titles be examined more closely in a further survey, since their abstracts suggest that they are highly relevant.

Inspection of scientific publications in the subject areas of sport and road safety showed that the stress events studied are not to be anticipated in the context of mechanical human-machine interfaces. It should also be noted that the corresponding results of stress lie well above a level that would be considered acceptable in occupational safety and health and could also be attained.

Of the 100 titles in the Access database, only 57 are of high relevance to occupational safety and health. Of these, 20 titles are to be found in the area of standardization and regulation. Ultimately therefore, 37 of the 450 inspected titles are of absolute benefit for assessment of the mechanical risk presented by collaborative robots. This ratio shows that very few useful stress variables and limits are available. Accordingly, a great need continues to exist for dedicated limits for assessment of the mechanical risks presented by collaborative robots.

4.7 Further comments

This section contains a number of additional comments on a range of aspects.

4.7.1 Use of human corpses in stress tests

The interval between the point in time of death and the point in time of the test (the postmortal interval) was not stated in any of the inspected titles included in the database in which stress tests were performed on human corpses or body parts; nor were any titles identified addressing tests performed on decomposed corpses or body parts.

The forensic pathologists significantly involved in performance of the KAN study are not aware of any relationship between the length of the postmortal interval and the mechanical properties of a corpse that has undergone no visible decomposition. It should further be noted that the results of tests performed on human corpses can never be extrapolated fully to living human beings, since the corpses lack a functioning cardiovascular system. For the development of biomechanical stress variables, the performance of stress tests on living test subjects is generally recommended, since such tests are ideally suited to transfer to preventive occupational safety and health activity. Preference should always be given to tests on living test subjects in this context.

4.7.2 Further development of the ICD

At the time of the KAN study, the International Classification of Diseases (ICD) was in its 10th edition. Publication of an 11th edition is expected; its publication date has however not yet been announced.

4.7.3 Terminology used in forensic medicine

The term "blunt force" is used in the subject area of forensic pathology.

The term refers to the nature of the injuries, from which conclusions are to be drawn concerning how they arose. The term should neither be taken literally (i.e. a cut with a blunt knife), nor (owing to the diversity of possible causes) should it be defined conclusively by case-based reasoning or in precise physical terms. [18]

Pointed, sharp and semi-sharp force is also a concept employed in forensic medicine.

The effect of pointed, sharp and semi-sharp force describes a particular form of mechanical damage which derives its characteristic from the geometry of the tool's contact surface and its movement relative to the surface of the body. The term "semi-sharp force" was coined in order to characterize intermediate stages between the injuries caused by sharp and blunt force. [18]

These terms are all useful for the classification of strains resulting from mechanical stress, including in other subject areas (such as that of occupational safety and health). The terminology is well established in forensic medicine and the judicial sector, but may be used differently elsewhere.

4.7.4 Funding schemes operated by the German federal government

The project contractors recommend that the German government be advised to fund the formulation of biomechanical stress variables and limits in the future. Programmes conceivable for this include:

- "Forschung für die Produktion von morgen" (technical programme)
- "IKT 2020 – Forschung für Innovationen" (technical programme)
- "IKT 2020 – Wissenschaftliche Vorprojekte zur Mensch-Technik-Interaktion für den demografischen Wandel"
- "InnoProfile-Transfer – Förderung von Forschungsgruppen und Verbundprojekten"

All current funding programmes can be viewed here:

http://www.foerderdatenbank.de

4.7.5 Inspection of the CITAVI database

In the course of the literature survey, a CITAVI database was created containing all the surveyed titles. This database can be accessed by means of the commercial CITAVI reader, which can be found at the following URL:

https://www.citavi.com/de/download.html

Use of the latest version is recommended.

5 Summary

The purpose of KAN Study 52, Biomechanical stress limits, was to ascertain and describe the current situation and the ongoing need for principles for mechanical risk assessment. The results of the study constitute a sound basis for future work and are useful to OSH experts and manufacturers as a source of data for the resolving of actual problems in risk assessment.

In the course of a literature survey conducted during the study, over 1,000 titles were identified as containing information on biomechanical stress limits falling within the scope of the study. The literature survey was conducted by means of dedicated tools and methods developed during the study. The relevant titles were archived with the aid of a literature management software application.

Altogether, specific stress-strain relationships were excerpted from 100 of the full complement of titles (totalling over 1,000), and entered into an Access database. An export function can be used to create a data fact sheet for each title in this database, containing all the information on the stress-strain relationships. Further titles can also be added to the database.

The overall result of the study shows that a strong need exists for biomechanical stress variables for use in future occupational safety and health activity. A large proportion of the inspected titles concerned stresses acting upon the occupants of passenger cars involved in road accidents. In all cases, the corresponding strains and injuries well exceeded the injury severity of "minor injury" that constituted the focus of the study. In addition, the stress types in a road accident differ from those that are to be anticipated in the event of a workplace collision with a robot.

Closer examination of the overall result also shows that the crucial stress variables for many strains and injuries are still unknown. In the area of minor injuries to soft tissue in particular, no validated and generally accepted conclusion has been reached regarding the crucial physical variables.

Besides the literature survey, the study also drew up proposals for how the new So injury severity category could be defined and how biomechanical stress variables or stress-strain relationships can be structured for the purposes of occupational safety and health.

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6 Literature

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7 Annex

7.1 Index of search terms

The key (German) search terms and their German and English synonyms are summarized in Table 16 to Table 22. The exclusion terms used to circumscribe the result set are shown in Table 22. Since case was ignored during all searches in the databases used, the terms listed here are stated in lower case irrespective of their orthography.

German synonym	English synonym
verletz*	injur*
trauma	trauma
schmerz	pain
schmerz	hurt
leid	harm
"klinische studie"	"clinical trial"
"klinische forschung"	"clinical research"
schmerztoleranzgrenze	"pain tolerance limit"
"leichte verletzungen"	"light injuries"
"leichte verletzung"	"light injury"
verletzungsvermeidung	"injury prevention"
verletzungsschwere	"injury severity"
"nicht-tödliche verletzungen"	"non-fatal injuries"
"nicht-tödliche verletzung"	"non-fatal injury"
"leichte verletzung"	"minor injury"
"leichte verletzungen"	"minor injuries"
wunde	wound
"traumatische verletzung"	"traumatic injury"
"physisches trauma"	"physical trauma"
druckschmerzschwelle	"pressure pain threshold"
druckschmerzschwelle	ppt
druckschmerztoleranz	ptol
druckschmerz	"pressure pain"

schmerzgrenze	"pain threshold"

Table 16 Key search term 1, "Verletzung" (injury)

German synonym	English synonym
verletz*	injur*
trauma	trauma
schmerz	pain
schmerz	hurt
leid	harm
"klinische studie"	"clinical trial"
"klinische forschung"	"clinical research"
schmerztoleranzgrenze	"pain tolerance limit"
"leichte verletzungen"	"light injuries"
"leichte verletzung"	"light injury"
verletzungsvermeidung	"injury prevention"
verletzungsschwere	"injury severity"
"nicht-tödliche verletzungen"	"non-fatal injuries"
"nicht-tödliche verletzung"	"non-fatal injury"
"leichte verletzung"	"minor injury"
"leichte verletzungen"	"minor injuries"
wunde	wound
"traumatische verletzung"	"traumatic injury"
"physisches trauma"	"physical trauma"
druckschmerzschwelle	"pressure pain threshold"
druckschmerzschwelle	ppt
druckschmerztoleranz	ptol
druckschmerz	"pressure pain"
schmerzgrenze	"pain threshold"

Table 17. Key search term 2, "Kraft"

German synonym	English synonym
grenzwert	limit
toleranz	tolerance
grenze	threshold
abgrenzung	bound*
maximalwert	"maximum value"

maxim*	max*
schwellwert	level
schwellenwert	"marginal value"
kriteri*	criteri*
score	score
höchstwert	"extreme value"

Table 18. Key search term 3, "Grenzwert" (limit)

German synonym	English synonym
biomech*	biomech*
biofidel*	biofidel*
biomedizin	"Biomedical engineering"
weichgewebe	"soft tissue"
"biomechanische belastungsgrenzen"	"biomechanical load limit"
kadaver*	cadaver
leichnam	corpse
"postmortales testobjekt"	"post mortem human subject"
"postmortales testobjekt"	pmhs
anthropomet*	anthropomet*

Table 19. Key search term 4, "Biomechanik" (biomechanics)

German synonym	English synonym
unfall	accident
arbeitsschutz	"occupational health"
arbeitssicherheit	"occupational safety"
sicherheitsanforderungen	"Safety requirements"
gefahr	danger
risiko	risk
risikobeurteilung	"risk assessment"
sicherheit	safety
risikofaktor	"risk factor"
	"risk factors"

Table 20. Key search term 5, "Unfall" (accident)

German synonym	English synonym
kontakt	contact
Impakt	impact
berührung	touch
kollision	collision
"physischer kontakt"	"physical contact"
"ungewollter kontakt"	"unintentional contact"
"stumper aufprall"	"blunt impact"
"stumpfes trauma"	"blunt trauma"
algometrie	algometry

Table 21. Key search term 6, "Kontakt" (contact)

German synonym	English synonym
tier	animal
krebs	cancer
medikament*	drug
blutdruck	"blood pressure"
simulation	simulation
rollstuhl	wheelchair
psych*	psych*
biochem*	biochem*
krankheit	disease
rückenmark	"spinal cord"
neuro*	neuro*
gehirn	brain
fem	"finite element"
veterin*	veterin*
pharma*	pharma*
toxi*	toxi*
diabet*	diabet*
automob*	automob*
sport	sport
obesitas	obesity
fettleibigkeit	adiposity
adipositas	adiposis

gefäß*	vas?ul*
operation*	surger*
kardi*	cardi*
bakterie*	bacteri*
allerg*	allerg*
patent*	patent
kronisch	chronic
kind*	child*

Table 22. Exclusion terms

7.2 Use of the Access database

7.2.1 System requirements

A Windows PC and Microsoft Office Version 2011 or later are needed for use of the Access database. The Office package installed must include Access. If this is not the case, Access can usually still be installed.

Basic familiarity with Access is recommended for use of the database.

7.2.2 Structure of the Access database

The database comprises a front end and a back end. The front end has the purpose of input and display of the data, the back end of storing these data. The data should always be accessed through the front end. The front end is stored in the <<iirob.accdb>> file, the back end in the <<iirob_be_accdb>> file.

These instructions are limited to a description of operation of the front end; knowledge of the back end is not required for use of the database.

7.2.3 Interface between front and back ends

When the database is first used, the front end must be linked to the back end:

- Open <<iirob.accdb>> in Access
- On the <External Data> tab, click on the **Linked Table Manager** {1} (Figure 18)

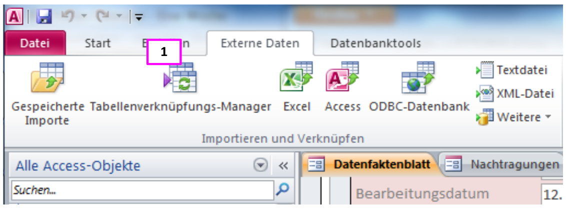


Figure 18. <External Data> tab

- The <Linked Table Manager> appears
- In the <Linked Table Manager>, click on **Select All** {1} and confirm with **OK** {2} (Figure 19)
- A file opening dialog appears
- Select the file <<iirob_be.accdb>> and confirm with OK
- The link between the front end and the back end has now been created

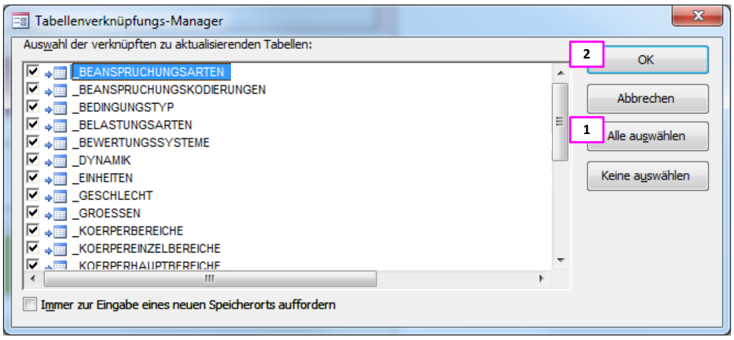


Figure 19. <Linked Table Manager>

7.2.4 Relevant elements in the front end

The front end comprises tables, forms and reports which can be called up via the left-hand navigation bar {1} (Figure 20).

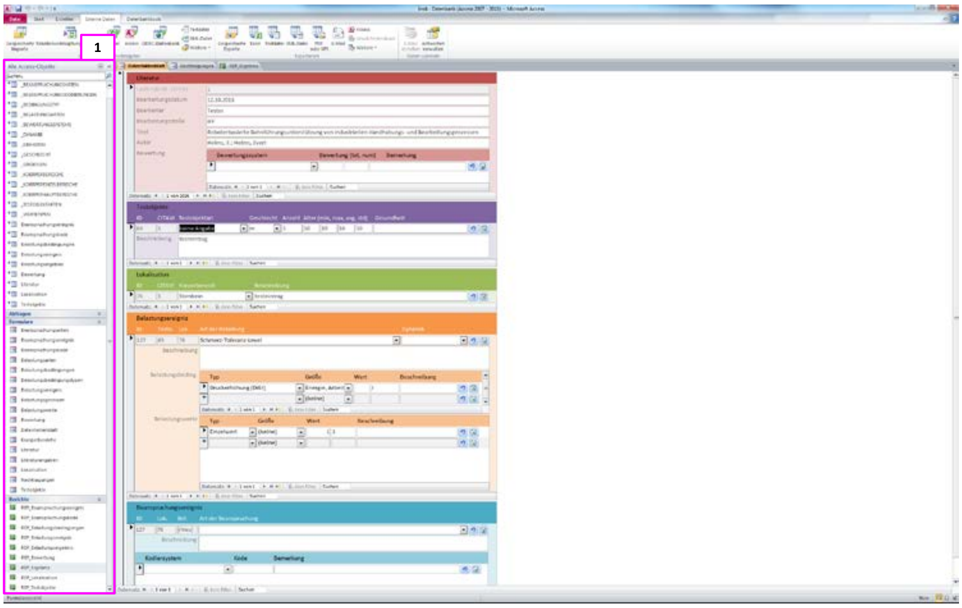


Figure 20. Navigation bar containing all relevant elements

The following elements are important for use of the database:

- <Literatur> (Literature) table {1} (Figure 21)
  - o Contains all titles entered into the database in table form, together with the most significant publication dates
  - o Was imported from the CITAVI database
- <Datenfaktenblatt> (Data fact sheet) form {2}
  - o Contains an input dialog (forms and sub-forms) by means of which the biomechanical stress test data can be loaded into the database
- <Nachtragungen> (Updates) form {3}
  - o Contains input dialogs by means of which additional selection data can be entered
- < REP_Ergebnis > (REP_Result) report {4}
  - o Contains a report on the entered data in the form of data fact sheets

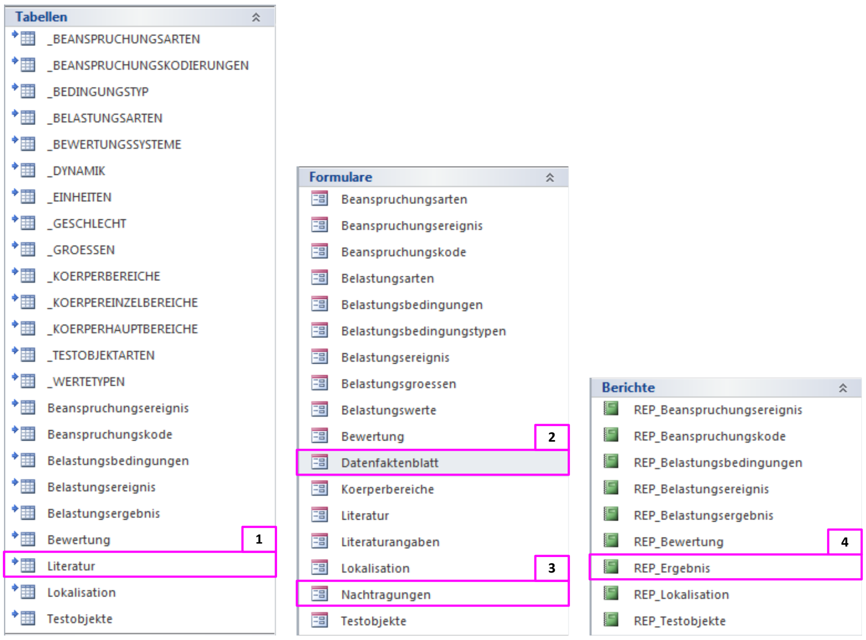


Figure 21. Relevant elements in the front end

7.2.5 Input of new data

The data from a stress test are input into the database by means of the <Data Fact Sheet> form. The data record number of the title from which the data are to be transferred to the database must first be determined:

- Open the <Literature> table by double-clicking on {1} (Figure 21)
- A table appears containing the complete bibliographical data of the surveyed titles
- Find the relevant title in the table and mark it
- Check which data record number {1} (Figure 22) is assigned to this title
- Note the data record number: it must be entered in {13} (Figure 25)

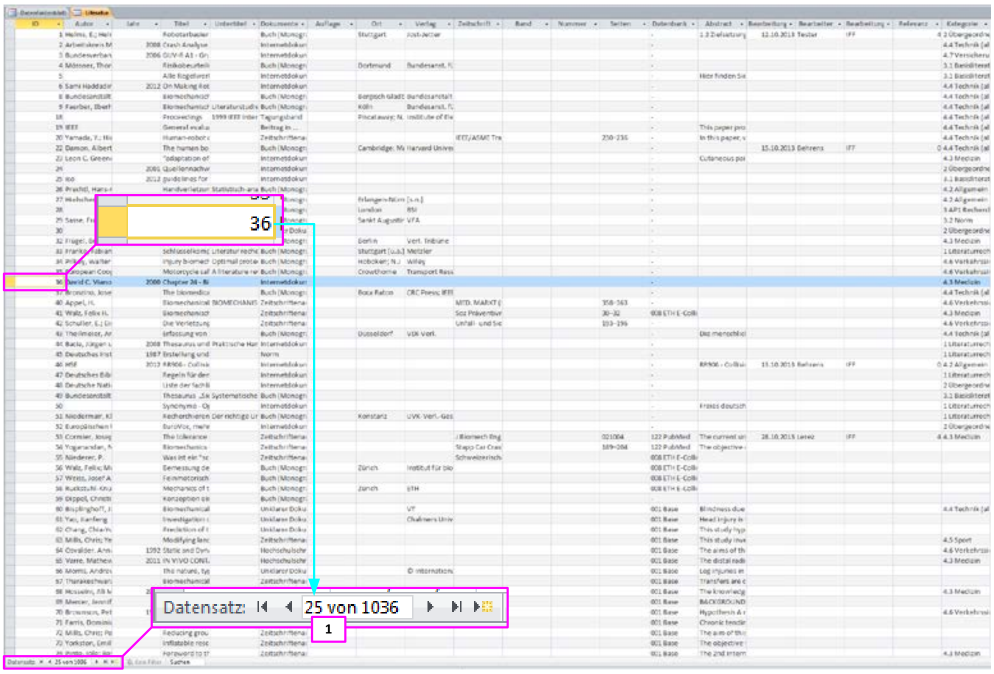


Figure 22. <Literature> table (the title with the ID of 36 has the data record number 25)

- Open the <Data Fact Sheet> form by double-clicking on {2} (Figure 21)
- The <Data Fact Sheet> form opens, on which all relevant data of a stress test can be entered

The <Data Fact Sheet> form is made up of the following sub-forms:

- <Literature>
- <Test Objects>
- <Localization>
- <Stress Event>
- <Strain Event>

Linking of the individual sub-forms is shown in Figure 23. All input fields in the sub-forms listed are presented below.

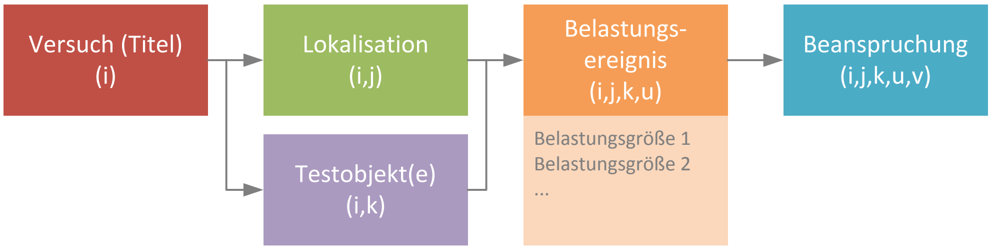
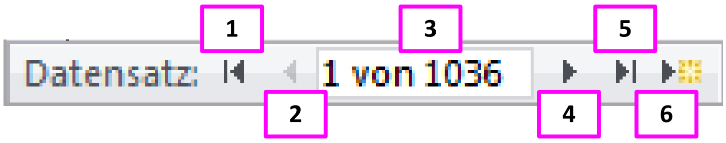


Figure 23. Relationship between the elements of an experimental test

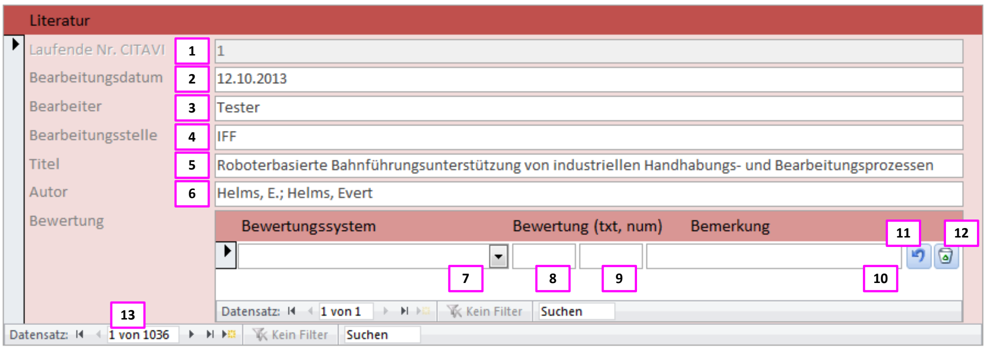
Navigation in the forms/sub-forms All data records which are linked as shown in Figure 23 can be called up by means of a sub-form. For navigation, Access provides a control bar, which is shown in Figure 24.



#	Explanation
1	Jump to first data record and show on form
2	Jump to previous data record
3	Number of the displayed data record (can also be entered directly)
4	Jump to next data record
5	Jump to last data record
6	Create a new data record

Figure 24. Navigation in sub-forms/forms

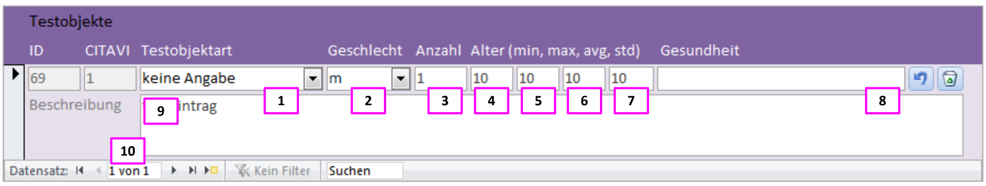
<Literature> sub-form This sub-form is used for selection of the publication the test data of which are to be input. Besides containing fields for editing information, the sub-form is also used for ranking of the publication as described in Section 3.3.4. All further elements are summarized in Figure 25.



#	Explanation
1	CITAVI-ID
2	Editing date (current date)
3	Name of editor
4	Name of editing body
5	Title of the active publication (cannot be edited)
6	Author of the active publication (cannot be edited)
7	Select ranking system (see Section 3.3.4)
8	Ranking (numerical, see Section 3.3.4)
9	(Not required for the existing ranking systems)
10	Comments on ranking (optional)
11	Undo input/change
12	Delete entry (warning: the entire entry will be deleted irretrievably)
13	Control bar for navigation between the publications: the data record number determined from the <Literature> table is entered here

Figure 25. <Literature> sub-form

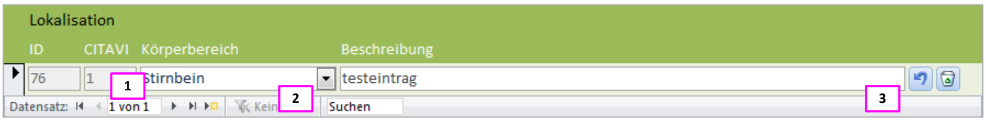
<Test objects> sub-form All information on the test objects used in the tests in the selected publication is entered on this sub-form. Note that a publication may contain multiple tests performed on different test objects. For this reason, multiple test objects can be associated with a single publication.



#	Explanation
1	Type of the test objects
2	Information on the sex
3	Number
4	Age (minimum)
5	Age (maximum)
6	Age (mean)
7	Age (standard deviation)
8	Comments on the health status (optional)
9	Description of the test objects (optional)
10	Control bar for navigation between the available data records (subsumed under the displayed publication in the <Literature> sub-form)

Figure 26. <Test objects> sub-form

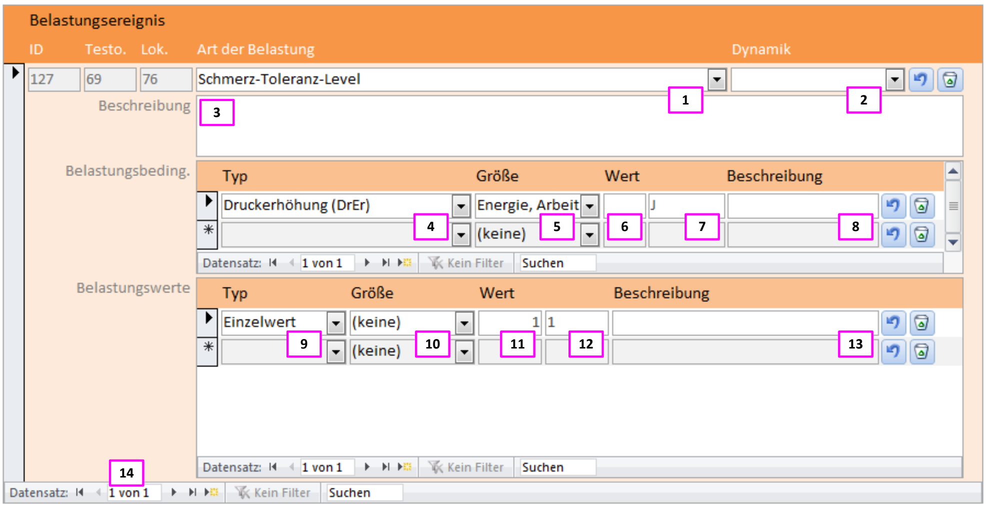
<Localization> sub-form This sub-form is used to indicate the localization on which the test objects stated were studied in the selected publication. Note that a publication may contain multiple tests performed on different localizations. For this reason, multiple localizations can be associated with a single publication. The stated localization must always relate to the data shown on the <Test Objects> sub-form.



#	Explanation
1	Control bar for navigation between the available data records (subsumed under the displayed publication in the <Literature> sub-form)
2	Selection of the body region
3	Description of the body region (optional)

Figure 27. <Localization> sub-form

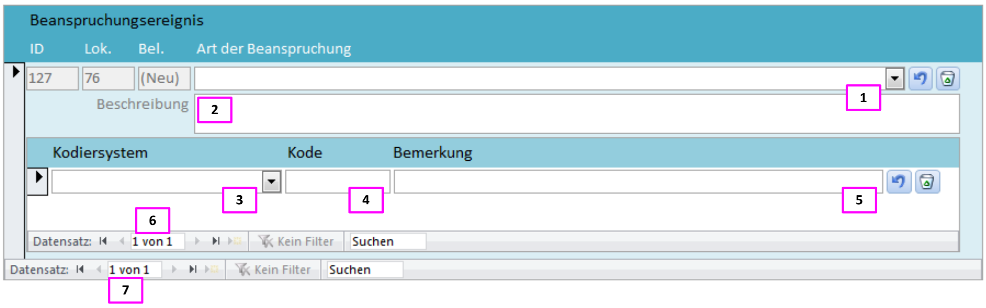
<Stress Event> sub-form All information on the stress event and its measured variables is entered on this sub-form. This entry relates to the data displayed on the <Test objects> and <Localization> forms. Note that multiple stress conditions (test variables) and/or stress values (measured values) can be stated for the stress event.



#	Explanation
1	Type of stress
2	Stress dynamics
3	Description of the stress (such as information on the test arrangement)
4	Type of the measurable stress conditions
5	Physical variable that can be assigned to the stress conditions
6	Value of the stress condition
7	Unit of the physical variable
8	Description of the stress condition
9	Type of stress value
10	Physical variable of the stress value
11	Numerical stress value/measured value
12	Unit of the physical variable
13	Description of the stress value
14	Control bar for navigation between the data records (subsumed under the displayed test objects and the displayed publication)

Figure 28. <Stress event> sub-form

<Strain event> sub-form Information on strain (the consequences of stress) is entered on this form. Multiple strains can be assigned to each stress event.

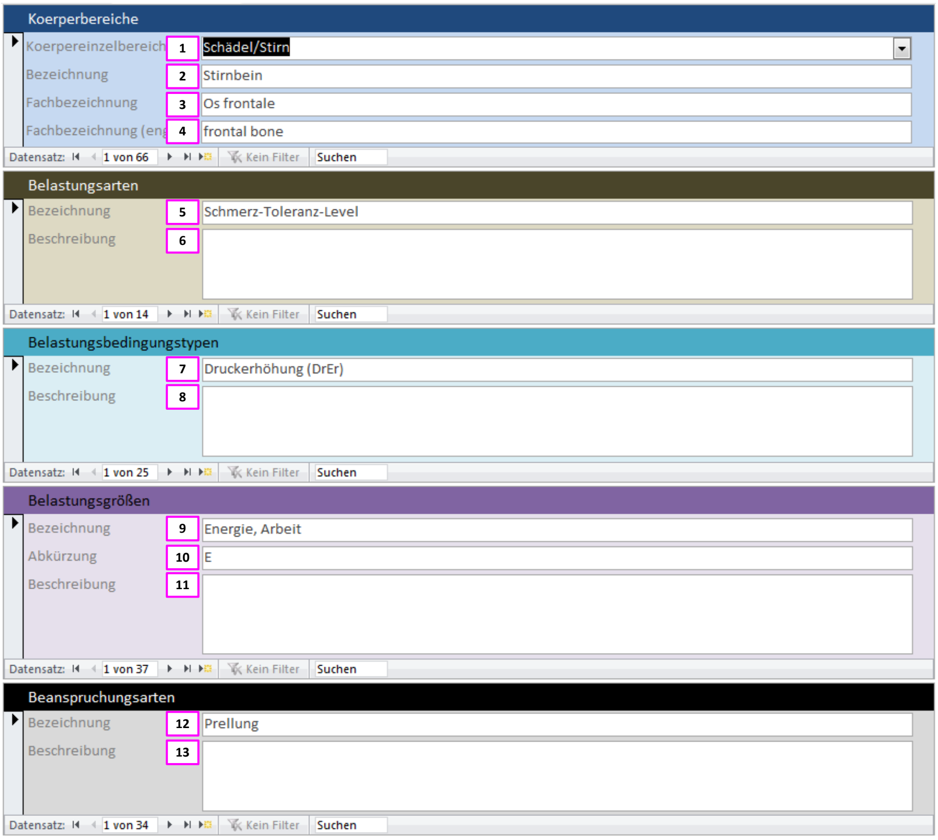


#	Explanation
1	Selection of the strain
2	Description of the strain
3	Selection of the coding system for classification of the strain
4	Code by means of which the strain can be described or characterized
5	Comment on the code
6	Control bar for navigation between the data records (subsumed under the displayed strain)
7	Control bar for navigation between the data records (subsumed under the displayed stress event)

Figure 29. <Strain Event> sub-form

7.2.6 Updated input of selection data (list data)

Certain content can be selected from lists in the sub-forms shown. The data contained in the lists can be updated on the <Updates> form.



#	Explanation
1	Selection of the specific region of the body in accordance with the body atlas of the IFA and the German Social Accident Insurance Institutions
2	German name of the new body region
3	German technical term for the stated body region
4	English technical term for the stated body region
5	German name of the new type of stress
6	Description of the stated type of stress
7	German name of the new stress conditions
8	Description of the stated stress conditions
9	German name of the new stress variable
10	Abbreviation for the stated stress variable
11	Description of the stated stress variable
12	German name of the new strain type
13	Description of the stated strain type

Figure 30. <Updates> form

Note that not all list data can be updated by means of the <Updates> form. If necessary, the updates can be made in the relevant tables.

7.2.7 Export of the results (data fact sheets)

The data entered can be exported in the form of data fact sheets by means of an export function:

- Right-click with the mouse in the navigation bar {1} (Figure 20) under <Reports> on <REP_Result> {4} (Figure 21)
- A context menu appears
- Click on **Page View** {1} (Figure 31)
- The data fact sheets appear

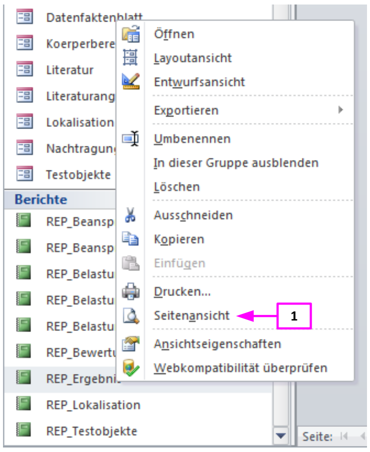


Figure 31. Generation of the data fact sheets

The data fact sheets can then be saved in PDF format:

- In the main menu, Click on the **PDF or XPS** menu item {1} (Figure 32)
- A file dialog appears
- Enter the file name with which the data fact sheets are to be saved
- Confirm with **OK**
- The data fact sheets are written to a PDF file

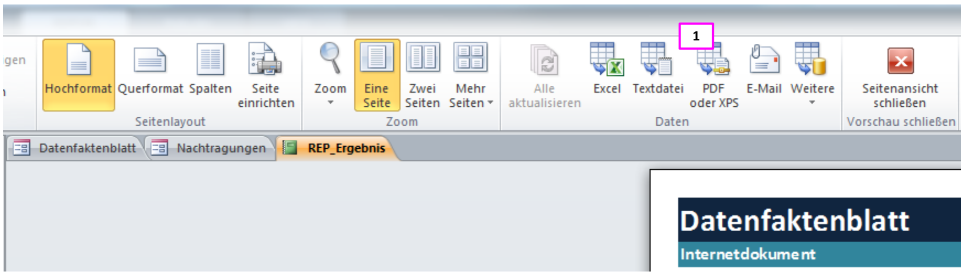


Figure 32. Saving the data fact sheets in PDF format

7.2.8 Structure of the data fact sheets

The data fact sheets contain the following information in the order shown:

- Bibliographical data
  - Document type (in accordance with Table 3)
  - Author
  - Title
  - Subtitle
  - Abstract
  - Year
  - Ranking
    - Technical ranking
    - Medical ranking
- Localization (more than one localization possible for each publication)
  - Code in the body atlas of the IFA/German Social Accident Insurance Institutions
  - Main body region in the body atlas of the IFA/German Social Accident Insurance Institutions
  - Specific body region in the body atlas of the IFA/German Social Accident Insurance Institutions
  - Name of the exact localization
  - Description of the localization
  - Stress event (more than one stress event possible for each localization)
    - Type of stress
    - Stress dynamics
    - Description of the stress
    - Stress conditions (more than one stress condition is possible for each stress event)
      - Type of stress condition
      - Physical variable of the stress condition
      - Value of the stress condition

    - Unit of the stress condition
    - Description of the stress condition
- Stress result (more than one stress result possible per stress event)
    - Type of stress value (measured value)
    - Physical variable of the stress value
    - Numerical stress value
    - Unit of the stress value
    - Description of the stress value
- Strain event (more than one result is possible per stress event)
    - Type of strain
    - Description of the strain
    - Coding of the strain
- Test objects subject to the stress (only one input possible per stress event)
    - Type of the test objects
    - Sex of the test objects
    - State of health
    - Number
    - Age (minimum)
    - Age (maximum)
    - Age (mean)
    - Age (standard deviation)
    - Description of the test objects

The quality of the data fact sheets in terms of their relevance to occupational safety and health is coded by means of a colour field in the title (to the right of the "Data Fact Sheet" title) in the same way as in Figure 12.

7.3 Assignment of the ICD-10 codes to the acceptable injuries from the proposed S0 definition

The tables below show the ICD-10 codes assigned to the two definition variants of the S0 injury severity category in Section 4.4.

Head injuries

Injuries included in the code	Description
S00.-	***Superficial injury of head*** 0 Type of injury not otherwise specified 1 Abrasion 2 Blister (non-thermal) 5 Contusion 8 Other

S00.0-[0,5,8]	Superficial injury of scalp
S00.3-[0,5,8]	Superficial injury of nose
S00.4-[0,2,5]	Superficial injury of lip and oral cavity NOTE Superficial puncturing of the mucous membrane must be excluded, since superficial injuries to the mucous membrane are likely to cause heavy bleeding. A consequence of this would be the inhalation of blood, which can lead to very severe breathing difficulties.
S00.8-[0,5,8]	Superficial injury of other parts of head

Neck injuries

Injuries included in the code	Description
S10.-	*Superficial injury of neck* 0 Type of injury not otherwise specified 1 Abrasion 2 Blister (non-thermal) 5 Contusion 8 Other
S10.0	Contusion of throat
S10.1-[0,8]	Other and unspecified superficial injuries of throat
S10.7	Multiple superficial injuries of neck
S10.8-[0,5,8]	Superficial injury of other parts of neck
S10.9-[0,5,8]	Superficial injury of neck, part unspecified

Injuries to the thorax

Injuries included in the code	Description
S20.-	*Superficial injury of thorax* 0 Type of injury not otherwise specified 1 Abrasion 2 Blister (non-thermal) 5 Contusion 8 Other
S20.0	Contusion of breast
S20.1-[0,2,8]	Other and unspecified superficial injuries of breast
S20.2	Contusion of thorax
S20.3-[0,2,8]	Other superficial injuries of front wall of thorax
S20.4-[0,2,8]	Other superficial injuries of back wall of thorax
S20.8-[0,2,5,8]	Superficial injury of other and unspecified parts of thorax (chest wall not otherwise specified, thoracic wall not otherwise specified)

Injuries to the abdomen, lower back, lumbar spine and pelvis

Injuries included in the code	Description
S30.-	*Superficial injury of abdomen, lower back and pelvis* 0 Type of injury not otherwise specified 1 Abrasion 2 Blister (non-thermal) 5 Contusion 8 Other
S30.0	Contusion of lower back and pelvis (buttocks, lumbar region, sacral region)
S30.1	Contusion of abdominal wall (epigastrium, flank, iliac region, inguinal region)
S30.2	Contusion of the external genital organs (labium (majus/minus), penis,

	perineum, scrotum, testes, vulva)
S30.8-[01,5,8]	Other superficial injuries of abdomen, lower back and pelvis
S30.9-[0,1,5,8]	Superficial injury of abdomen, lower back and pelvis, part unspecified

Injuries to the shoulder and upper arm

Injuries included in the code	Description
S40.-	***Superficial injury of shoulder and upper arm***
S40.0	Contusion of shoulder and upper arm
S40.7	Multiple superficial injuries of shoulder and upper arm

Injuries to the elbow and forearm

Injuries included in the code	Description
S50.-	***Superficial injury of forearm***
S50.0	Contusion of elbow
S50.1	Contusion of other and unspecified parts of forearm

Injuries to the wrist and hand

Injuries included in the code	Description
S60.-	***Superficial injury of wrist and hand***
S60.0	Contusion of finger(s) without damage to nail
S60.2	Contusion of other parts of wrist and hand

Injuries to the hip and thigh

Injuries included in the code	Description
S70.-	***Superficial injury of hip and thigh***
S70.0	Contusion of hip
S70.1	Contusion of thigh

Injuries to the knee and lower leg

Injuries included in the code	Description
S80.-	***Superficial injury of lower leg***
S80.0	Contusion of knee
S80.1	Contusion of other and unspecified parts of lower leg

Injuries to the ankle and foot

Injuries included in the code	Description
S90.-	***Superficial injury of ankle and foot***
S90.0	Contusion of ankle
S90.1	Contusion of toe(s) without damage to nail (contusion of toe(s) not otherwise specified)
S90.2	Contusion of toe(s) with damage to nail
S90.3	Contusion of other and unspecified parts of foot

Injuries involving multiple body regions

Injuries included in the code	Description
T09.0-	*Superficial injury of trunk, level unspecified*
T09.05	Contusion
T11.0-	*Other injuries of upper limb, level unspecified*
T11.05	Contusion
T13.0-	*Other injuries of lower limb, level unspecified*
T13.05	Contusion

7.4 Glossary

List of terms (including key search terms) to which reference can be made if needed for the harmonization of technical terminology. The English technical terms are stated in alphabetical order together with their German equivalents.

Accident	Unfall
algometry	Algometrie
anthropometry	Anthropometrie
Biofidel	biofidel
biomechanics	Biomechanik
biomedical engineering	biomedizinisches Engineering
blunt impact	stumpfer Aufprall
blunt trauma	stumpfes Trauma
Cadaver	Kadaver, Leichnam
clamping force	Klemmkraft
clinical research	klinische Forschung
clinical trial	klinische Studie
collision	Kollision
contact	Kontakt
contact force	Kontaktkraft
crush force	Quetschkraft
Failure load	Grenzlast
Impact	Aufprall
impact force	Auftreffkraft
injury criteria	Verletzungskriterium
injury prevention	Verletzungsvermeidung
injury severity	Verletzungsschwere

Level	Schwellwert
light injury	leichte Verletzung
limit	Grenzwert
load	Belastung
load limit	Belastungsgrenze
Minor injury	leichte Verletzung
Non-fatal injury	nicht-tödliche Verletzung
Occupational safety	Arbeitssicherheit, Arbeitsschutz
Pain threshold	Schmerzgrenze
pain tolerance limit (PTOL)	Druckschmerztoleranz
physical contact	physischer Kontakt
physical trauma	physisches Trauma
pinch force	Kneifkraft
post mortem human subject (PMHS)	postmortales Testobjekt
pressure	Flächenpressung
pressure pain	Druckschmerz
pressure pain threshold (PPT)	Druckschmerzschwelle
risk assessment	Risikobeurteilung
Safety requirements	Sicherheitsanforderungen
shear force	Scherkraft
shock	Impact
squeezing force	Quetschkraft
stress	Druck
Threshold	Grenze
tolerance	Toleranz
trapping force	Klemmkraft
trauma	Trauma
trauma score	Traumascore, Traumaskala
traumatic injury	traumatische Verletzung
Unintentional contact	ungewollter Kontakt