XJENZA ONLINE

VOLUME 10 ISSUE 1, 2022

The University of Malta Research, Innovation & Development Trust

MALTA CHAMBER OF SCIENTISTS

www.xjenza.org

Science Journal of the Malta Chamber of Scientists

Editor-in-Chief: Cristiana Sebu

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Scope of Journal

Xjenza Online is the Science Journal of the Malta Chamber of Scientists and is published in an electronic format. Xjenza Online is a peer-reviewed, open access international journal. The scope of the journal encompasses research articles, original research reports, reviews, short communications and scientific commentaries in the fields of: mathematics, statistics, geology, engineering, computer science, social sciences, natural and earth sciences, technological sciences, linguistics, industrial, nanotechnology, biology, chemistry, physics, zoology, medical studies, electronics and all other applied and theoretical aspect of science.

The first printed issue of the journal was published in 1996 and the last (Vol. 12) in 2007. The publication of Xjenza was then ceased until 2013 when a new editorial board was formed with internationally recognised scientists, and Xjenza was relaunched as an online journal, with two issues being produced every year. One of the aims of Xjenza, besides highlighting the exciting research being performed nationally and internationally by Maltese scholars, is to provide a launching platform into scientific publishing for a wide scope of potential authors, including students and young researchers, into scientific publishing in a peer-reviewed environment.

Instructions for Authors

Xjenza is the Science Journal of the Malta Chamber of Scientists and is published by the Chamber in electronic format on the website: http://www.mcs.org.mt/index.php/xjenza. Xjenza will consider manuscripts for publication on a wide variety of scientific topics in the following categories

1. Research Articles
2. Communications
3. Review Articles
4. Notes
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9. Errata

Research Articles form the main category of scientific papers submitted to Xjenza. The same standards of scientific content and quality that applies to Communications also apply to Research Articles.

Communications are short peer-reviewed research articles (limited to three journal pages) that describe new important results meriting urgent publication. These are often followed by a full Research Article.

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The manuscript will be divided into clearly defined and numbered sections. Each numbered subsection should have a brief heading. Each heading should appear on its own separate line. Subsections should be used as much as possible when cross-referencing text, i.e. refer to the subsection by the section number.

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McCreadie, C. and Tinker, A. (2005). The acceptability of assistive technology to older people. *Ageing Soc.*, 25(1):91–110.

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Fisk, M. J. (2003). *Social Alarms to Telecare: Older People's Services in Transition.* Policy Press, Bristol, 1st edition.

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Sebu, C. (2022). *Xjenza Online*, 10(1):1.

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Editorial

In Our Commitment to Science

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Dear readers and authors of Xjenza Online, as Editor-in-Chief, I am very pleased to announce the release of the first regular issue of 2022 of Xjenza Online.

I am very glad that this year, with the valuable assistance and contribution of the two dedicated and skilful copy editors of Xjenza Online, Julia Curmi and Josse Schubert, the journal was able to start releasing Online First the articles accepted for publication in a timely manner, a tangible evidence of our commitment to the ongoing improvement of the services we provide.

The issue opens with a study by Cutajar et al. on the moving patterns of five loggerhead sea turtles (Caretta caretta) rescued in Maltese waters and rehabilitated at the Aquaculture Directorate at Fort San Luċjan. The GPS tracking revealed that the turtles frequented the same main region to the South of the Maltese islands, typically the Libyan and Tunisian neritic coastal zones covered similar mean distances (11.2–22.4 km/day), despite differences in their life-stages and physical abilities.

The following article by Agius et al. focuses on the self-reported stressors and experiences of Maltese dental academics during the COVID-19 pandemic. The results of an anonymous survey showed that the academics accepted the online platforms for lecturing and examinations, but they were highly concerned about the lack of students' practice during the lockdown which cannot be compensated by online tutoring.

Next, Camilleri et al. identifies the risk factors of aortic valve replacement using two types of frailty models (i.e. shared and unshared). The participants in this study were patients who underwent an aortic valve replacement procedure at a Maltese hospital between 2003 and 2019. The dependent variable is the duration till death or till censored and the eleven predictors provide information about the patients' health condition, surgery operative procedures, and duration of convalesce period.

Subsequently, yet another reflection of how much the Covid-19 pandemic affected the world's population. Diacono et al. assessed the impact of Covid-19 on healthcare workers and front-liners working in Malta including stress levels, work load, and their psychological well-being, while emphasizing the need for enhanced support from government entities, education and awareness regarding mental health and available assistance.

The paper by Theuma and Abela then estimates price multipliers and their decomposition effects for the Maltese economy, based on the 2010 micro social accounting matrix. Importantly, these price multipliers provide a first cut estimate of assessing price effects in terms of intermediary input costs, wages costs and cost-of-living adjustments following exogenous cost changes.

The issue concludes with a review by Abela et al. on the recent developments in the use elastomers for orthopaedic implants. The range of applications of elastomers vary from hip joint replacements, meniscal implants, and first metatarsophalangeal joint replacements. Typically, silicones, polyurethanes and hydrogels are preferred due to their good mechanical properties, chemical resistance and biocompatibility, but there are other promising emerging materials such as polycarbonate urethanes.

To conclude, as today's research is a global endeavour, so remains our commitment to serve the local professional scientific community.

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Cutajar, M. et al. (2022). *Xjenza Online*, 10(1):2–14.

Xjenza Online: Science Journal of the Malta Chamber of Scientists
www.xjenza.org
DOI: 10.7423/XJENZA.2022.1.01

Research Article

Tracking *Caretta caretta*: Movement patterns following rehabilitation in Malta

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Abstract. GPS tracking through the use of satellite transmitters has proved to be a useful technology in identifying migratory patterns in juvenile and adult sea turtles, despite being a relatively new tool in behavioural biology. This technology has allowed tracking to take place over larger areas and for longer periods of time than previously possible. Loggerhead sea turtles (*Caretta caretta*) are able to travel over large distances throughout their life, being able to travel up to 13,000 km in one year, visiting distant areas and often demonstrating complex patterns of movement both as juveniles and adults. However, information on the tracking of loggerhead turtles rehabilitated and released from the Maltese islands is scarce. This study followed the paths taken by five loggerhead sea turtles, four of which were juveniles while one was a full male adult. All turtles were rescued in Maltese waters and rehabilitated at the Aquaculture Directorate at Fort San Luċjan. The turtles spent between 205 and 1550 days at the rehabilitation centre, depending on the severity of their injuries. Three of these turtles were missing either a front or a hind limb. Turtle movements were recorded as X-Y coordinates using Argos System Applications. This information was gathered using Collecte Localisation Satellite (CLS). Following release, all five turtles were observed to frequent the same main region to the South of the Maltese islands, typically the Libyan and Tunisian neritic coastal zones, with few discrepancies also being recorded. The maximum daily speed recorded ranged between 2.4 and 8.0 km/h. The total distance travelled by the turtles under study ranged between 1375 km and 3273 km in 92 and 292 days respectively. The five turtles covered similar mean distances (11.2–22.4 km/day), despite differences in their life-stages and physical abilities. These results suggest that despite their physical limitations, turtles having missing limbs moved at speeds and covered distances comparable to their fully able counterparts.

Keywords: Loggerhead turtle, *Caretta caretta*, GPS, Satellite, Tracking, Mediterranean, Malta

1 Introduction

In the Mediterranean Sea, loggerhead turtles (*Caretta caretta*), together with other species of sea turtles, are of conservation interest and have been afforded protection since the late 20th Century. Loggerhead sea turtles are able to travel several thousands of kilometers throughout their lives, visiting distant areas feeding in neritic or oceanic zones, and demonstrating complex patterns of movement both as juveniles and as adults (Luschi et al., 2013). Knowledge of movement patterns of turtles out at sea are required for effective and efficient conservation management of this species (Casale et al., 2018). Accurate data on movement patterns can be obtained through satellite tracking. This is a relatively new technology, and its application for tracking the movement of loggerhead turtles in the Mediterranean Sea started merely three decades ago (Hays et al., 1991). While there were some problems with the earliest attempts at satellite tracking of loggerheads, developments in the technology were made in a relatively short period of time. GPS tracking of sea turtles by satellite transmitters has since proved to be useful technology in assessing migratory patterns in juvenile and adult turtles over large areas and over longer periods of time than previously possible (Bentivegna, 2002). Satellite tracking has also allowed for the identification of various short- and long-distance movements to be recorded and correlated to specific life stages of this species. Different studies (Bentivegna, 2002; Bentivegna et al., 2007; Bradai et al., 2009; Casale et al., 2018) all identified seasonal migratory routes, with loggerheads moving from the

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western Mediterranean basin to the eastern parts of the Mediterranean in autumn. Similarly, migrations from the northern parts of the basin to the southern parts have also been observed. Casale et al. (2018) identified several pathways which loggerheads follow throughout their life. Migratory pathways along shallow areas, namely along the southern Mediterranean coast, the northern parts of the Adriatic Sea and along the western coast of Greece were identified. Migratory funnels in open water have also been identified as turtles frequent such areas throughout the reproductive season. Most of the previously identified migratory corridors lie in the East part of the Mediterranean basin (Bentivegna et al., 2007; Casale et al., 2018). The Maltese islands lie within some of the migratory funnels identified by Casale et al. (2018), thus tracking of turtles from the Maltese islands is of interest as one can identify the routes taken by these turtles and whether the routes taken correspond to previously identified migratory corridors. The period of activity of the satellite signalling varies, depending on the life stage of the individual, with younger turtles losing the tracking device earlier, because their shell scutes undergo more frequent developmental changes than adults. The first eleven years of a loggerhead sea turtle are characterised by an increased dependence on oceanographic and meteorological conditions. As the loggerhead grows and develops its muscular apparatus, an increased independence from these factors arises (Bentivegna et al., 2007). Adult females have been observed to perform cyclical shuttling migrations between foraging and breeding sites, thought to be the same routes followed by males (Luschi et al., 2014; Luschi et al., 2013). Their navigational conduct has been attributed to environmental cues, such as thermal fronts and marine currents (Bentivegna et al., 2007). Satellite tracking is also an important tool when following turtles with a disability arising from severe injuries for which they would have undergone treatment and rehabilitation. Turtles easily get caught in derelict fishing lines and nets, as well as large pieces of plastic litter, derelict nylon, twine and ropes, most times becoming severely entangled. As the turtle keeps swimming the entanglement becomes more severe, tightening around the flippers and/or carapace. Often this results in the disruption of the blood flow into the distal part of the limb, resulting in loss of the flipper. It is assumed that this would affect normal activities such as diving and swimming over long distances. It may also effect male *C. caretta* when digging for bivalves and during mating (Schofield et al., 2006). The loss of any flipper shall definitely effect nesting females as they make use of all four flippers in pit preparation, to dig their egg chamber and to direct the eggs from the cloaca into the pit (Hailman et al., 1992). Publication of studies in the recent past have returned differentiating results between rehabilitated loggerhead turtles and patterns recorded for wild unrehabilitated loggerheads (Cardona et al., 2009). Such a comparison has not yet been done on turtles rescued and rehabilitated in Malta, and thus this study will also contribute information towards this knowledge gap. Since the loggerhead, *C. caretta*, is the most abundant sea turtle species in the Mediterranean, it is not surprising that this species is the one that is most encountered in Maltese waters. Occasional nesting events have also been registered on beaches across the Maltese archipelago over the past decade (ERA, 2021; Pace, 2021). Loggerhead turtles in Maltese waters fall victim to both active and derelict fishing gear, boat injuries and ingestion of litter namely plastic and hooks and lines. The associated injuries are the most treated at Nature Trust FEE Malta's Wildlife Rehab Centre. Tracking of turtles in Malta has to date involved mainly rescued, rehabilitated turtles during their release back into the marine natural environment. Sea turtles have a low survival probability, with only 1 in every 100 hatched turtles (Frazer, 1986) reaching maturity. Therefore, understanding the life strategies of these reptiles is important for effective conservation efforts and management. It is also important to understand how these life strategies and survival probability can be affected by injuries and periods of rehabilitation (Baker et al., 2015). Understanding how rehabilitated individuals of *C. caretta* perform following rehabilitation compared to unrehabilitated counterparts, can determine whether rehabilitation efforts are being done in an efficient manner without disturbing the animal's natural instincts. This is in fact what this study aims to contribute, while also comparing migratory routes for juvenile and adult specimens. The first published tracking instances from Malta occurred in 2008 through ERA, formerly Malta Environment and Planning Authority (MEPA) (Hochscheid et al., 2011). This tracking was part of a Regional Activity Centre for Specially Protected Areas (RAC/SPA) project with the collaboration of the Istituto Zoologico di Napoli, MEPA and Veterinary Regulation and Fisheries Conservation and Control Division of Malta. The 2008 tracking involved two rehabilitated turtles which had suffered different injuries. Zeus was the bigger of the two turtles and had suffered mild injuries, thus needed care for a few months. Vicky, which had suffered severe head and neck injuries and had its left front flipper amputated, was released following years at the rehabilitation centre (ERA, 2013). Zeus was recorded as mainly residing in the Malta-Sicily channel during the period of tracking (seaturtle.org, 2013). Unfortunately, the data for Vicky are no longer available on the RAC/SPA website (seaturtle.org, 2013). The present study presents satellite telemetry for five loggerhead turtles which were rescued from different sites and all were rehabilitated prior to release. The turtles were at different stages of their life-cycle with four being juveniles and one adult. Tama, the sole adult male turtle, was missing a front left flipper on release. Doris, one of the juveniles was missing her left hind flipper on release, similarly to Carmine which was also missing one of her rear flippers. Janis and Alison were not missing any flippers on release. Thus, the aim of this study was to assess whether migratory patterns in juveniles and adults overlap, and whether specimens suffering from loss of different flippers behave differently from fully able specimens. This study aims to assess whether turtles that have undergone amputation of one or more of their flippers differ in the migratory routes and speeds from fully bodied, rehabilitated turtles and wild specimens of *Caretta caretta*.

2 Materials and Methods

Malta is located in the South-Central region of the Mediterranean Sea, 80 km south of Sicily and 241 km east of Tunisia. The Maltese coast is mainly rocky, with just 2.4% of the coastline being sandy beaches (Deidun et al., 2004). The high light-pollution on these beaches and the ever-increasing marine traffic in Maltese waters are some of the challenges that loggerheads face when in these waters. In fact, during 2021, Nature Trust FEE Malta, recorded the highest number of rescues for loggerhead turtles ever, since it first started rehabilitating injured *C. caretta* individuals back in 2001. Water temperature in Malta normally falls below 21°C in December, and is back up to this temperature in June, making the release season rather long. This helps with maintaining periods of rehabilitation low, thus rehabilitated turtles are often released soon after they have been declared healthy by the veterinary surgeon in charge.

The five turtles included in this study were rescued between 2015 and 2019, and were released in the years 2018 and 2019 table 1. All turtles were rescued following reports by fishermen, boatmen and the general public of the turtles being in distress, with the main injuries being caused by marine debris and fishing gear. The turtles were rehabilitated at the rehab centre under care for an extensive period of time, depending on the severity of the injuries and the turtle's progress, and were only released once it was determined that the turtles were capable of surviving in the natural environment.

Sandy beaches in Malta are limited and as a result most releases are organised from one of the few beaches present, usually either from Ġnejna Bay or Għajn Tuffieħa Bay in Malta or from Ramla l-Ħamra or Ħondoq ir-Rummien Bay in Gozo (table 1). Prior to release, each turtle in this study was equipped with an ARGOS-linked Satellite transmitter, model SPOT6. The transmitters (Platform Transmitter Terminals, PTTs) were attached to the top of the carapace using epoxy resin in accordance with the 'Attachment Protocol Kit' (Wildlife Computers, 2008). The PTT for each turtle was set to transmit once or twice daily, depending on the satellite route. The period of transmission varied from one specimen to the other, depending on their development and maturity of the specimen as the tracker is lost once the outer carapace layer matures. Each turtle was also equipped with a microchip, which was inserted on the medial margin of the left hind flipper. This would enable identification of the turtle following the loss of the tracker if it is injured once again and/or returns to Maltese beaches (table 1).

Turtle movements were recorded as X-Y coordinates making use of Argos System Applications. Argos system applications allow tracking of organisms as information is relayed over the Argos Satellite system. This information is gathered using Collecte Localisation Satellite (CLS) which is the developer of the processing tools and services which distribute the raw data to the user, Nature Trust Malta in this case (Argos, 2021). Once the trackers stopped generating a daily signal, a notification was received and the data were downloaded in the comma delimited format (.csv). The data were cleaned by removing repetitive geolocation data points that fell along a single straight line on the same day for a given turtle. This was done to ensure that points plotted on the maps were not overcrowded resulting in lack of clarity in travel paths. The clean set of points were imported into ArcGIS software version 10.6.1 (Esri Inc, 2017) for further processing. Position waypoints showing the movement recorded for each turtle were plotted, and a map showing all turtle routes superimposed over each other was also generated to identify any common zones or patterns. Maps were generated using the Management Tools function, which converted the individual geolocation into continuous lines. The daily and total distance travelled by each turtle was also calculated using the formula developed by Vincenty (1975), based on an ellipsoidal model of the Earth (Vincenty, 1975). This formula is accurate to 1 mm on an ellipsoid model, however accuracy is lower when used on a WGS-84 system, as was done in this case. Thus, the results obtained are an indication of the distances travelled by each turtle to around ±1m (Veness, 2019). The distances obtained using this calculation were counterchecked with the distances between points on ArcMap GIS and were reconfirmed using Google Earth. This was carried out, to ensure that the data obtained are accurate and correspond to the distances travelled by the turtles. The raw data recorded for distance travelled daily was used to assess whether any statistically

Microchip ID	Name	Date of recovery	Site of recovery	Life stage and gender	Clinical condition on arrival	CCL (cm)	CCW (cm)	Wt (kg)	Veterinary Treatment	Duration of rehabilitation period (days)	Date of Release	Site of Release
900182001135067	Carmine	16/12/2016	Marsaxlokk	Juvenile	Injury left hind flipper (swollen with exposed bone). Entangled with a rope, pieces of net and a branch of a tree	35	31	3	Amputated left hind flipper	738	24/12/2018	Ħofriet, Xrobb l-Għaġin, Marsaxlokk Malta
900182001135300	Doris	22/05/2017	Offshore landed at Kalkara	Juvenile	Severe damage to right hind flipper from restriction with exposed bone. Entangled in nylon bag	38	36	5	Amputated left hind flipper	568	11/12/2018	Għadira Bay,
990000002586219	Alison	27/05/2018	2 Km North of St Paul's Bay	Juvenile	Fishing line extending out of mouth and cloaca	43	42	7	Surgical removal of fishing hook	205	18/12/2019	Ħondoq ir-Rummien Bay,
990000002586433	Janis	24/02/2019	Marsamxett Harbour	Juvenile	Hook in gullet and entanglement with fishing line	42	40	8	Surgical removal of fishing hook	249	31/10/2019	Għajn Tuffieħa, Mġarr Malta
990000002585436	Tama	19/09/2015	Off Comino	Adult male	Propellor strike – multiple injuries to left front flipper, neck and shoulder	63	58	37	Amputated left front flipper	1550	16/12/2019	Ġnejna, Mġarr Malta

Table 1: Turtle weight (kg) Curved Carapace Length (CCL; cm) and Curved Carapace Width (CCW; cm) upon arrival at the rescue centre and duration (days) spent at the rescue centre.

Microchip ID	Name	Tracker Registration Number	Date of end of signal	Days of transmission
900182001135067	Carmine	Tracker SPOT 6 No84234	17/05/2019	145
900182001135300	Doris	Tracker SPOT 6 No84233	21/04/2018	130
990000002586219	Alison	Tracker SPOT 6 No196950	20/03/2020	92
990000002586433	Janis	Tracker SPOT 6 No195996	15/02/2020	106
990000002585436	Tama	Tracker SPOT 6 No197241	Still transmitting	292*

Table 2: Details of the tracker registration number installed on each turtle, the day of release and the number of days for which a signal was generated by the tracker.

*Still transmitting, 292 calculated up to 3rd October 2020 significant difference exists at a 95% confidence interval between the different turtles, whether varying in their life stage or whether they have suffered a disability due to the injuries sustained. This was done through a 'Generalised linear model' using SPSS v.27 (IBM Corp, 2020). The raw data for the 'distances travelled' daily for all turtles throughout the tracking period was tested for normality and following the failing of these tests, the non-parametric Gamma distribution was opted for. The Gamma distribution is very assumption light and can be run on continuous data as was the data format being analysed here. Different turtles were defined as different categories, such that the analysis was based on groups of data pertaining to each individual turtle, rather than considering each value as a different turtle. The mean distance travelled by each turtle was obtained through the 'mean' calculation, based on the summation of all travelled distances, divided by the number of transmission days of the tracker for the respective turtles. For Tama, the 'days of transmission' was taken to be 292 days as the tracker was still generating a signal at the time of writing.

3 Results

General patterns were derived for five rehabilitated individuals, after tracking them for at least 92 days. The duration of the tracked period varied for the five turtles under study and this could be due to either loss of tracker by accident or loss of tracker through natural life processes. None of the trackers involved in this study registered malfunction. Two of the turtles spent most of their time in the sea South of the Maltese Islands, while one (Janis) spent most of its time in the Malta-Sicily channel and North East of the Maltese Islands. Alison also deviated from the general pattern, spending a few days in the Malta-Sicily channel, but then headed south soon after the first few weeks of tracking. Carmine headed west towards Tunis immediately after release then proceeded to the North West of the Mediterranean towards Sardinia and continued further towards Spain (figure 1). All five turtles were released during the autumn season, with Janis released in October, while the other four were all released in December, albeit in different years (table 1).

Most turtles in this study were juveniles, whilst Tama was the only adult turtle. The routes taken by the turtles seem to overlap for the most part throughout the tracking period. Carmine was the only turtle that deviated from this general pattern, heading to the NW of the Mediterranean where it spent most of its time throughout the tracking period. The results generated after running the data through a Generalised Linear Model for all turtles, after having defined each turtle as its own category, returned a statistically non-significant difference in the distance travelled by juveniles and adults (p-value; $0.545 > 0.05$) (Appendices). This suggests that adults and juveniles are able to cover similar distances throughout their life-cycle. From the Generalised Linear Model using a Gamma distribution, it was also concluded that there was no statistically significant difference in the distance (km) covered daily by fully able turtles and those suffering a disability (p-value; $0.566 > 0.05$) (Appendices). The Generalised Linear Model supported the fact that turtles having missing limbs showed similar distances as recorded by fully bodied turtles. Table 3 highlights how Carmine, which was missing a limb, recorded the highest maximum distance (km) travelled in one day and the highest average distance (km) travelled over its tracking period These numbers are comparable to those recorded for Janis, which was not missing any limbs on its release. Similarly, the numbers are comparable for Alison and Doris, although lower than those recorded for Carmine and Janis, reinforcing that there is no difference between fully bodied turtles and ones missing limbs.

4 Discussion

Satellite tracking has proved to be the most efficient method presently available to visualise movements of marine organisms, a technology that has been used to study migrations of sea turtles for several years (Nielsen et al., 2009). Until recently, data on the migrations of loggerhead turtles rehabilitated and subsequently released in Malta was somewhat scarce, with information available being restricted to that noted in Hochscheid et al. (2011). The present study aims at filling some of the gaps related to movement of this species, which is currently listed as vulnerable in the IUCN red list. Loggerhead turtles are highly migratory, poikilothermic organisms and their distribution and behaviour are dependent on the surrounding environment. Thus, the migratory routes these reptiles follow are affected by shifting temperatures, currents, habitats and food availability (Mansflield et al., 2013). Warmer Mediterranean waters are found to the South of the Maltese islands due to the natural thermogradient present in the Mediterranean Basin. *Caretta caretta* migration routes are influenced by water temperature and thus it is a common phenomenon that turtles migrate to warmer waters during the colder months (Bentivegna, 2002). The results presented in this study corroborate such findings as most turtles released in Autumn headed southward during the colder months of tracking. However, this was not always the case as Carmine migrated toward the North West of the Mediterranean basin following a few weeks close to Tunisia. Carmine migrated towards the NW colder regions of the Mediterranean in early March, when water temperatures would not have yet star-

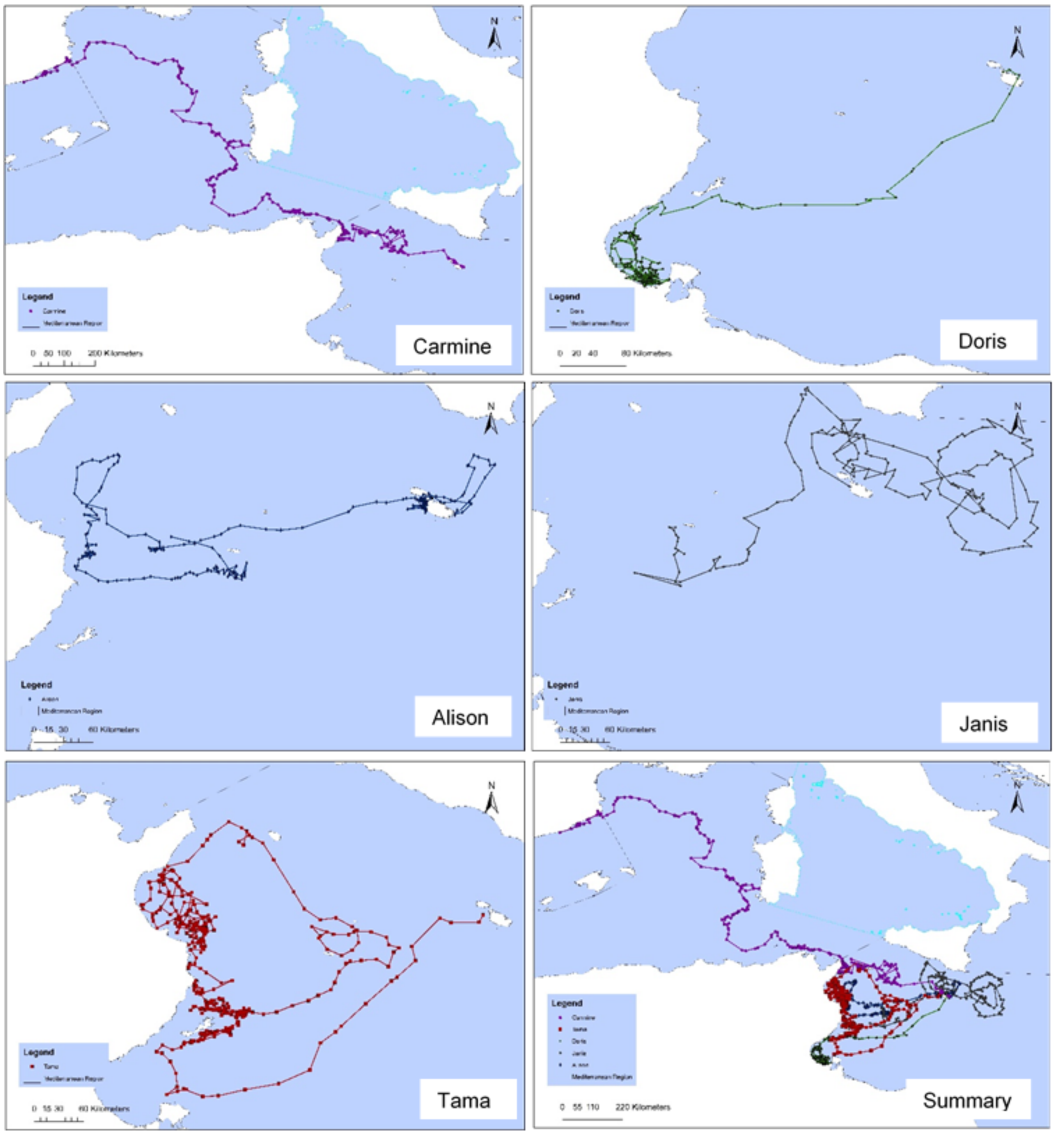

Figure 1: Map of the route taken by the five turtles tracked. Carmine was released from Għajn Tuffieħa Bay Mġarr, Malta with the PTT transmitting for 145 days. Doris was released from Għadira Bay Mellieħa, Malta and the signal transmitted for 131 days. Alison was released from Ħondoq ir-Rummien Bay, Qala Gozo, with the PTT transmitting for 92 days. Janis was released from Għajn Tuffieħa Bay Mġarr, Malta with the signal transmitting for 107 days. Tama was released from Ġnejna Bay Mġarr, Malta with the signal still transmitting at the time of paper submission. In the case of Tama the data mapped is for the first for 292 days of transmission. Maps were generated using ArcMap GIS 10.6.1

Microchip ID	Name	Maximum distance travelled in one day (km)	Minimum distance travelled in one day (km)	Maximum speed recorded (km/h)	Total distance travelled (km)	Total days tracked	Average distance travelled per day of tracking (km)
900182001135067	Carmine	191.4	0.1	8.0	3253.9	145	22.4 ± 24.0
900182001135300	Doris	57.8	0.3	2.4	1879.6	130	14.2 ± 10.6
990000002586219	Alison	67.0	2.0	2.8	1375.1	92	14.9 ± 12.6
990000002586433	Janis	101.6	2.0	4.2	2346.1	106	21.7 ± 18.2
990000002585436	Tama*	61.2	0.5	2.6	3273.1	292*	11.2 ± 10.6

Table 3: Table showing the distance travelled calculated for each turtle. The table indicates the maximum and minimum distances travelled in a day by each turtle during tracking (km), the maximum speed with which the turtle travelled (km/h), the overall distance travelled by each turtle (km) and the average distance travelled by the turtle during the tracking period (km).

*The data for Tama was calculated based on the first 292 days of tracking as the tracker is still generating a signal on submission of this paper for publication.

ted to rise. This study shows that within the central Mediterranean rehabilitated loggerhead sea turtles with missing appendages (*Caretta caretta*) travel long distances that are comparable to those travelled by full able-bodied specimens. Such distances and areas in which the tracked individuals travelled all fall within the main migratory corridors identified by Casale et al. (2018). It is also evident that some of the turtles tracked in this study followed similar routes to turtles tracked under the RAC/SPA project as outlined in Hochscheid et al. (2011). When referring to the map showing the route taken by 'Zeus' (Mifsud, 2020; seaturtle.org, 2013) similarities are apparent with the route taken by Janis, both residing in the Malta-Sicily channel for most of their tracked days. Comparison with the data for Vicky, the second turtle released during the RAC/SPA project, is not possible as data for this turtle are no longer available. With the exception of Carmine, all turtles travelled and resided for long periods of time within the neritic regions in Tunisian and Libyan waters (figure 1). Neritic areas are areas corresponding to the continental shelf and are generally delimited by the 200m isobath (Casale et al., 2018). The neritic regions identified in Casale et al. (2018) have been identified as foraging and wintering areas, thus providing possible explanations to the migratory routes undertaken by the five turtles tracked in this study, despite Carmine migrating to the Spanish coast soon after its arrival at the Tunisian coast. However, this is not necessarily an anomaly as the Spanish continental shelf shows the same neritic characteristics as the Libyan and Tunisian coasts (Cardona et al., 2009), despite temperature variations between the western and southern coasts of the Mediterranean. Carmine was also released on the 24th December 2018 and travelled to the South of the Mediterranean towards Tunisia and as temperatures rose towards the end of the tracking duration for this turtle, it migrated towards the NW, were temperatures tend to be cooler for a longer period of time. These findings support the findings by Cardona et al. (2009), with the latter having identified that the majority of rehabilitated turtles tracked in their study, spent their time in the neritic regions, with just one of the tracked turtles migrating into oceanic waters. This identifies a fidelity between rehabilitated turtle and neritic feeding areas. Whether this is a result of rehabilitation has not yet been investigated experimentally, however several findings have suggested this behaviour not being an artefact of rehabilitation. Aerial surveys by Cardona et al. (2009) and Gómez de Segura et al. (2006) identified a higher density of loggerhead sea turtles in different neritic regions across the Mediterranean.

Carmine and Janis registered the highest maximum distances travelled in one day and also the highest mean distance travelled per day during the tracking period (table 3). Tama, Alison and Doris recorded similar mean distances to one another (table 3). The lowest overall mean daily distance travelled was observed for Tama, the only adult. However, when analysed for statistical significance through a Generalised Linear Model, the difference between distances recorded by the different turtles at different life-stages, were observed to not be statistically significant. These findings are comparable to results recorded for *Caretta caretta* adult individuals previously tracked within the Mediterranean (Bentivegna, 2002). Bentivegna (2002) recorded mean distances between 10 km and 23 km for adult *C. caretta* fully-bodied individuals which were released following rehabilitation for a few months after being rescued from trawl nets. However, out of the five turtles tracked in this study, only Tama was a full adult with the rest being juveniles (table 1). Comparable results for the overall mean daily distance travelled, were also recorded for Tama when considering the first 145 days of tracking, which is equivalent to the maximum number of days of tracking undertaken for the other four turtles (mean distance/day based on 145 days of tracking = 10.2 ± 10.9). The present results indicate that juvenile individuals reflect the behaviour and capabilities of adult specimens. Moreover, three of the five turtles considered during the present study had missing limbs and, despite their physical limitation, these turtles moved with speed and covered distances comparable to their fully bodied counterparts. Therefore, the comparison of the mean distance travelled does not show distinctive differences between specimens with loss of hind flippers and fully bodied ones. Tama an adult, missing a front flipper, recorded a maximum travelling speed comparable to Alison, a full-bodied juvenile and Doris a juvenile turtle missing one of its hind flippers. Carmine, who was also missing a rear hind flipper, recorded the maximum travelling speed and showed the highest mean distance travelled per day over the tracking period. The maximum distance recorded for this turtle was not a one-off, it actually travelled almost an equal distance also on the day after registering the maximum distance travelled. This could also be explained by the fact that the turtle was in open waters where speeds achieved are much higher than those in neritic areas (Casale et al., 2018). Some studies show that after long periods of rehabilitation, turtles were returned with success in their natural environment (Robinson et al., 2020). The outcome of this study supports this theory. The tracking records obtained for the five turtles subject of this paper are strong evidence of the distance and speed capabilities of rehabilitated turtles. Further tracking data, particularly on adult individuals will serve to provide more information on the migrations undertaken by this species. Releases in different seasons will allow for the comparison of travel patterns between seasons.

5 Conclusion

The routes taken by all turtles led to areas, in particular the neritic regions in Tunisian and Libyan waters, which were common to all, suggesting grounds of importance, possibly as foraging and mating grounds within the regions highlighted in previous publications. It appears that loss of any one flipper does not affect the activity of the turtle and foraging for food and general movement seem to follow the capabilities of the fully bodied specimens. Our results highlight that the rehabilitation of these five marine turtles and their return to their natural environment, seems to have been a success in particular for Tama, Carmine and Doris in spite of the long period of rehabilitation.

6 Acknowledgements

We would like to thank the Department of Fisheries and Aquaculture for the use of facilities at San Luċjan Tower, Marsaxlokk that has allowed adequate rehabilitation of the turtles under our care. We would also like to thank the numerous volunteers who have in the past worked and others who still work in the rehabilitation centre providing the care needed by these turtles. Thanks, are also due to ERA, Armed Forces of Malta (AFM) Marine Unit, Civil Protection Department and the Administrative Law Enforcement Section (ALE) of the Malta Police Force and members of the general public who have been involved in the recuperation of the turtles cared for by NTM. The writers also would like to thank Prof. Liberato Camilleri who aided in the assessment of significance of the data presented in this study and Mr John J. Borg, senior curator of the National Museum of Natural History for his availability and assistance in examining the specimens attributable to Despott. Lastly, we would like to thank Singita Miracle Beach, Lidl, MAPFRE Middlesea, Emanuel Delicata Wine Maker LTD and other organisations and individuals for their financial support to be able to purchase the PTTs used for the tracking of these turtles, without whom such an endeavour could not be undertaken.

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Appendices

Generalised Linear Models

Model Information	
Dependent Variable	Distance
Probability Distribution	Gamma
Link Function	Identity

Case Processing Summary		
	N	*Percent*
Included	735	100.0%
Exluded	0	0.0%
Total	735	100.0%

Categorical Variable Information				
			N	*Percent*
Factor	Disability	Disability	545	74.1%
		No Disability	190	25.9%
		Total	735	100.0%
	Life Stage	Adult	286	38.9%
		Juvenile	449	61.1%
		Total	735	100.0%

Categorical Variable Information						
		N	*Minimum*	*Maximum*	*Mean*	*Std. Deviation*
Dependant Variable	Distance	735	10	191.40	16.4785	16.29504
Covariate	Turtle	735	1	5	3.37	1.567

Goodness of Fit[a]			
	Value	*df*	*Value/df*
Deviance	571.388	731	.782
Scaled Deviance	817.154	731	
Pearson Chi-Square	630.528	731	.863
Scaled Pearson Chi-Square	901.731		
Log Likelihood[b]	-2743.348		
Akaike's Information Criterion (AIC)	5496.695		
Finite Sample Corrected AIC (AICC)	5496.777		
Bayesian Information Criterion (BIC)	5519.694		
Consistent AIC (CAIC)	5524.694		

Omnibus Test[a]

Likelihood Ratio Chi-Square	*df*	*Sig.*
69.317	3	.000

Test of Model Effects

		Type III	
Source	*Wald Chi-Square*	*df*	*Sig.*
(Intercept)	6.859	1	.009
Disability	.330	1	.566
Life Stage	.366	1	.545
Turtle	.435	1	.510

Parameter Estimates

			95% Wald Confidence Interval		Hypothesis Test	
Parameter	*B*	*Std.Error*	*Lower*	*Upper*	*Wald Chi-Square*	*df*
(Intercept)	24.042	6.8979	10.522	37.561	12.148	1
[Disability=1]	-2.714	4.7275	-11.980	6.551	.330	1
[Disability=2]	0[a]	.	.	.	.	.
[Life Stage = 1]	-4.052	6.6947	-17.173	9.070	.366	1
[Life Stage = 2]	0[a]	.	.	.	.	.
Turtle	-1.178	1.7855	-4.677	2.322	.435	1
Scale	.699[b]	.0331	.637	.767		

Parameter Estimates

	Hypothesis
Parameter	*Sig.*
(Intercept)	.000
[Disability=1]	.566
[Disability=2]	
[Life Stage = 1]	.545
[Life Stage = 2]	
Turtle	.510
Scale	

Agius, A.M. et al. (2022). *Xjenza Online*, 10(1): 15–22.

Xjenza Online: Science Journal of the Malta Chamber of Scientists
www.xjenza.org
DOI: 10.7423/XJENZA.2022.1.02

Research Article

Self-reported stressors and experiences of Maltese dental academics during the COVID-19 pandemic

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Abstract.

Aim.

To compare self-reported outcomes among dental faculty members during the COVID-19 pandemic.

Materials and Methods.

An anonymous questionnaire consisting of 13 closed and open-ended questions was sent to all faculty members (n=41) in the Faculty of Dental Surgery at the University of Malta. Categorical (Likert-scale) and qualitative questions on self-reported outcomes were identified and tallied. Non-parametric tests were used to correlate and compare variables among the different genders, departments and roles of the academics (i.e. full-time, part-time, visiting and demonstrators).

Results.

Thirty-two (32) out of forty-one (41) academics completed the online questionnaire. A satisfactory adaptation to online lecturing was noted from the majority of the participants. On the other hand, full-time faculty members were significantly more anxious about contracting COVID-19 than part-time and visiting faculty members ($p = 0.020$). Most participants were concerned about the lack of practical training opportunities for students. There were no significant differences between gender categories for any of the variables explored in this study ($p > 0.05$).

Conclusion.

Academics accepted online platforms for lecturing and examinations as viable alternatives to traditional methods for theoretical learning but they were highly concerned about the possibility of students losing their practical skills during the lockdown and that online tutoring cannot compensate for lost hands-on time in preparation for their upcoming practical examinations. They, however, recognized the benefits of blended modes of tuition in the future.

Keywords: COVID-19, dental students, stress, anxiety

1 Introduction

The current COVID-19 pandemic has had a significant impact on people's lifestyle and work. In this context, among the most affected are healthcare facilities and workers; and this is especially true for oral health care professionals who routinely carry out intraoral procedures which generate aerosols. In an effort to control transmission, healthcare facilities adopted new measures, equipment and enhanced personal protective equipment (PPE) to be able to keep providing care for their patients (A. M. Agius et al., 2020; Ather et al., 2020; Izzetti et al., 2020; Meng et al., 2020). Further to the changes in the provision of care mentioned above, there were significant general changes to behaviours internationally. Due to the high transmission rate of SARS-CoV-2, considerable social distancing actions such as country-wide lockdowns and border closures were introduced worldwide. Similarly, educational institutions were required to perform major changes or close down for a period of time until they could successfully reopen with the required safety measures in place. Educational institutions in Malta were closed down during the first wave of the pandemic—March to September 2020—and this included the only dental school in the country. Academics and students alike had to quickly adapt to new online teaching platforms and assessment methods which added further stress to an already challenging curriculum (A. Agius et al., 2020). Upon re-opening, science-related academic institutions needed to adopt even more safety measures, such as patient swabbing before attendance, reduced number of patients in clinical areas and waiting rooms, increased fallow time leading to reduced time of clinical sessions, changes in PPEs, as well as in ventila-

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tion and air filtration systems, among others (as per the faculty guidelines issued in 2020). For dental schools, high transmission rates of SARS-CoV-2 have been reported, mostly due to the challenge to safely treat patients routinely, especially when considering dental treatments that generate aerosols (Ren et al., 2020). Consequently, recent studies have reported a severe impact of this new reality on self-reported outcomes such as stress and anxiety in dental students and professionals. Little, however, is known about the effects of the pandemic on the aforementioned outcomes in faculty members of dental schools. Thus, this study aimed to compare self-reported outcomes among dental faculty members from different departments and with different roles within the university, during the current pandemic.

2 Materials and Methods

Sample

This cross-sectional study was conducted involving academics from the Faculty of Dental Surgery, University of Malta. All participants signed informed consent allowing the anonymous use of collected questionnaire data. This study was approved by the local Ethics Committee (Protocol number: DSG/2019–2020/009). The STROBE guidelines for cross-sectional studies and the Helsinki Declaration guidelines were also carefully observed during the research. Failure to submit the questionnaire was the only exclusion criterion. The data were collected between the 11th and the 17th of May 2020.

Questionnaire

The anonymous questionnaire consisted of 24 questions to gather both quantitative and qualitative data (table 1). Most questions were closed-ended, in the form of multiple-choice questions, checklists, or Likert scales (Attard et al., 2018). Also included were four open-ended questions to allow academics to express themselves better and discuss any issues or topics that were not covered within the other questions. The only demographic data requested were, their role within the university, department section and gender, with the option to choose "other" if they felt this could potentially identify them due to small numbers. The faculty's secretary forwarded a link to the questionnaire hosted on Google Forms to all academics. This ensured the anonymity of data. Automatically gathered responses into Google Forms and a data sheet was generated in Microsoft Excel. These data were then cleaned and coded. The resulting quantitative data were tabulated and used for statistical analyses, whereas the qualitative data were analysed by studying the different emergent themes from every answer and the number of times these themes featured in the data collected (Masood et al., 2010).

Statistical Analysis

The sample size was previously estimated with Noether's formula (Noether, 1987), to give the study a statistical power of 80% within a significance level of 5%. Multiple-choice questions were treated as qualitative variables and were compared among groups using the chi-square test. Questionnaire data obtained from Likert scales, in turn, were treated as categorical ranks and therefore assessed using the Kruskal-Wallis test. Results from all variables obtained from the questionnaire were compared among academic members with different roles in the university (full-time resident academic, part-time resident academic, visiting academic, and clinical demonstrator) and among different departments within the Faculty of Dentistry (Oral Rehabilitation and Community Care, Dental Surgery, Restorative Dentistry, and Child Dental Health & Orthodontics). Additional comparisons between participants of different genders were assessed. Finally, nonparametric correlations between categorical variables observed through the questionnaires were assessed using the Spearman's Test. A $p < 0.05$ significance level was used for all the tests. All statistical analyses were performed with the same software (SPSS 22.0; SPSS Inc, Chicago, IL, USA).

3 Results

The questionnaire was distributed to all 41 academics working within the Faculty of Dental Surgery at the University of Malta. This is considered a total population of dental academics in Malta as this is the only dental school in the country to date. Thirty-two (32) academics completed the online questionnaire whilst nine (9) academics did not and were therefore excluded from the study. The response rate was that of 78%. The respondents were 50% male (n=16) and 43.8% female (n=14). Two participants preferred not to disclose their gender to preserve their anonymity. There were no significant differences between gender categories for any of the variables explored in this study ($p > 0.05$). Regarding university appointment, the majority of respondents (56.3%, n=18) were visiting academics, 21.9% (n=7) were full-time resident academics, 15.6% (n=5) were part-time resident academics and 6.3% (n=2) were those who only did clinical demonstration. The distribution of academics within the four faculty departments can be seen in figure 1.

Online Teaching Methods

Participants were asked about their experiences regarding the transition to online lecturing. There was an overall positive response with 15.6% (n=5) saying they did very well and they prefer online teaching to the usual teaching methods. However, the majority of academics (68.8%, n=22) reported the experience was 'good overall' but they prefer 'in-person' teaching methods. A few academics (12.5%, n=4) said the experience was 'the same overall' and they do not feel they had any preference towards teaching online or in-person, whilst one academic responded that the online experience was very bad and it was difficult to connect with students and communicate on camera. Nevertheless, most of the lectures were ultimately delivered, even during the period of the pandemic assessed herein (figure 3). Lecture output increased to almost 100% during most weeks with the first week being the worst. Most participants (87.5%, n=28) were concerned students would lose their practical (manual) skills and training during the lockdown period. They also showed concern that the Faculty teaching clinics would probably not start functioning again upon re-opening of the university and other educational institutions within the country due to the changes needed in equipment, facilities and PPE in light of the pandemic. When asked about how participants felt about working from home/off-site, there was a very balanced distribution of answers with 31.3% (n=10) who responded 'better', 31.3% (n=10) who responded 'the same' and 37.5% (n=12) who responded 'worse'. An open-ended question further explored the reason for their answers. Academics responded that while they preferred not having to commute to University in traffic and face parking issues, they also missed the in-person interaction with students during lectures and were worried about the lack of contact time with regards to clinical practice. Academics were also asked how they think this pandemic will change the way they deliver lectures long-term. Common answers that emerged were there should be a combination of online teaching and in-person clinical training so that students and educators alike can benefit from the advantages of both methods.

Stress-related Factors

Academics were asked a series of factors that could cause anxiety during the pandemic and they chose answers from a Likert scale ranging from "Strongly agree" to "Strongly disagree". The highest anxiety-provoking factors (defined as those factors with a majority of "agree" or "strongly agree" answers) were "fear about a family member contracting COVID-19" (75%, n=24), "not being able to meet the students in person" (87.5%, n=28), "major changes required at the teaching clinic in relation to COVID-19 which will result in a delay in re-opening" (59.3%, n=19). Full-time faculty members were significantly more anxious about contracting COVID-19, than part-time and visiting faculty members ($p = 0.020$, figure 2). When asked about their coping strategies in an open-ended question, several common themes emerged, namely: living day-by-day but keeping oneself occupied with housework and re-discovering hobbies, countryside walks and exercise, catching up on home projects and preparing lectures and examinations.

Academics' concerns regarding students

Academics were asked for their thoughts regarding upcoming examinations and novel methods of assessment and a number of common themes emerged. Academics were most concerned about the possibility of students having connectivity problems during online examinations, lack of timely face-to-face communication, increased student stress during this examination period compounded by the changes in assessment methods, concerns regarding the possibility of students cheating, and students not being well-prepared for practical examinations due to lack of clinical time. Eighty-eight percent (n=28) of academics were concerned students would lose their manual dexterity and practical skills during the university lockdown. The rest believed the students would recover these skills in time (12%, n=4).

Correlations between categorical variables

Several relevant and significant correlations have been found among the variables analysed in the questionnaires. Anxiety of contracting COVID-19 was moderately inversely correlated with experience with online lecturing ($R = -0.437, P = 0.012$) and with concerns of losing training ($R = -0.421, P = 0.016$) and directly correlated with feeling anxious most of the time ($R = 0.408, P = 0.023$). Similarly, a direct moderate significant correlation was found between not being able to work as much as used to, and anxiety most of the time ($R = 0.494, P = 0.005$). Furthermore, moderate to strong direct correlations were detected between not being able to meet students and concerns about reopening time ($R = 0.583, P = 0.001$) and changes ($R = 0.596, P = 0.001$) in the teaching clinic. All other correlations assessed herein were not significant ($P > 0.05$).

Suggestions for the faculty

A couple of open-ended questions regarding faculty improvements needed for re-opening of the dental teaching clinics resulted in a number of suggestions. The commonest suggestions were to re-consider cross-contamination procedures and ventilation systems, enhanced PPE for aerosol-generating procedures, better timely communication with students regarding fast-paced changes in their theoretical and practical teaching, examination methods and platforms and more individual support for students when they return to the teaching clinics.

4 Discussion

The present cross-sectional study assessed self-reported outcomes on dental academics during the COVID-19 pandemic. Results indicated the majority of the participants were considerably affected by the current pandemic regarding self-reported stress, which corroborates previous studies about health-care educators (Kaup et al., 2020). Among the concerns reported by the majority were that students would lose their clinical skills due to lack of training and those related to the reopening of the teaching clinic. Such findings are in agreement with a previous study about students from the same dental school reporting similar concerns and who were also affected significantly during the pandemic (A. Agius et al., 2020). Similarly, situations reported herein, such as the impact on dental practitioners of the lack of PPE, have also been reported in literature (Tysiąc-Miśta et al., 2020). On the other hand, acceptability of online lecturing from dental academics was in general satisfactory. Among the primary explanations given for this is the dental faculty provided training and guidance documents with immediate effect upon the physical closing down of all academic institutions of the country. As a result, most faculty members could adapt to the technology advances necessary and to continue the theoretical teaching. Very few experienced problems with connectivity or delivery during the lectures, however, most still preferred face-to-face lectures due to better communication and rapport with the students. In this context, similar findings have also been reported from dental students (A. Agius et al., 2020). This supports the usefulness of online lecturing during the current pandemic and the possibility of combining modes of tuition even after the pandemic. Furthermore, this is the first article describing the concern of not being able to meet the students in person as one of the main factors impacting self-reported outcomes of dental academics during the pandemic. Similarly, participants were also concerned about the possible late re-opening of teaching clinics due to having to make significant changes to the facilities, protocols and student clinic time-tables. Following several meetings and suggestions with students and academics alike, the faculty worked hard and fast to transition to online examinations, creating protocols and planning training sessions for academic and administrative staff and students. New ventilation and air filtration equipment was installed in all teaching clinics, improved PPE was bought and provided. Student clinic timetables were changed to have fewer students, patients and staff present at any one time to respect social distancing measures. Students were given the opportunity to practice more in simulation dental laboratories to make up for reduced clinic time. Clinical time was spread throughout the day to allow for more regular albeit shorter sessions for each student. A COVID-19 swab test was also being requested for all patients being seen at the dental teaching clinic, whilst clinic staff and students were asked to present a swab test result every two weeks. It can be anticipated that although the pandemic is still raging and the scenario is currently worse than when this study was carried out, due to the organizational, technological and people-oriented changes the faculty implemented, one might anticipate the academic staff concerns and anxieties related to new teaching methods and the ability to reach out to students and safety might be less however student anxieties related to their learning and target acquisition might still be the same. For academic staff there was a steep learning curve in online teaching and examining skills which might have caused some anxiety but which will serve to improve the operations of the faculty beyond the pandemic. One of the limitations of this study is that it is cross-sectional and it examined academics' experiences only during one period of the on-going pandemic. The sample size is also small, even though the response rate is high, as this is the only dental school in a small country (Malta). In future, further studies regarding the experiences of academics and students during the second phase of the pandemic would be interesting to note any possible changes in their perspectives and challenges. Future studies and comparisons with other dental schools worldwide would also provide interesting data and learning experiences the impact of the COVID-19 pandemic on dental academics.

5 Conclusion

Academics accepted online platforms for lecturing and examinations as viable alternatives to traditional methods for theoretical learning but they were highly concerned about the possibility of students losing their practical skills during the lockdown and that online tutoring cannot compensate for lost hands-on time in preparation for their upcoming practical examinations. They, however, recognized the benefits of blended modes of tuition in the future. Academics also voiced concerns regarding the Faculty's ability to safely re-open teaching clinics with new protocols and equipment in place in time for training for practical examinations. Rapid training of academics to adapt to online teaching helped in having a smooth and quick transition while avoiding significant consequences to the lecturing profile and student curriculum of this dental school.

6 Acknowledgements

Ms Rachel Caruana, Faculty Secretary for questionnaire distribution.

7 Conflict of Interest

None of the authors have any conflict of interest regarding this study. There was no funding provided for this study.

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Appendices

Category	Questions	Type of answers
Demographics	Gender	Multiple choice answer
	What is your role within the University?	Multiple choice answer
Current changes	Which department do the majority of the modules you teach fall under?	Multiple choice answer
	Rate your experience with regards to online lecturing	Multiple choice answer
	How would you describe your experience of working from home/ off-site?	Better The Same Worse
	How do you think this will affect your teaching methods long-term, if at all?	Open-ended question
	Do you have any particular problems or concerns regarding the student examinations?	Open-ended question
	Do you have any particular problems or concerns regarding the students losing training or skills?	Yes/No/Other
	Do you feel that the lost time should be compensated for with additional study time?	Yes/No/Other
	Can you suggest any improvements for the Faculty to consider?	Open-ended question
	Do you think the Faculty will need to reconsider all cross-infection procedures?	Yes/No/Other
	I feel anxious most of the time	Likert Scale
Mental and emotional well-being	I am anxious of contracting COVID-19	Likert Scale
	I am worried that one of my family members contracts COVID19	Likert Scale
	This has affected my personal relationship with my partner	Likert Scale
Student Concerns	This has affected my relationships with family	Likert Scale
	This has affected my relationships with friends and work colleagues	Likert Scale
	I worry about not being able to work as much as I used to	Likert Scale
	I don't like not being able to meet my students in person	Likert Scale
	I feel more stressed about having to deliver all my lectures online	Likert Scale
	I am more anxious about preparing the examinations this year because of the challenges we're facing	Likert Scale
	I am concerned about losing my manual dexterity skills because I haven't been able to practice as much	Likert Scale
	Not being in a University/hospital environment has affected my aptitude for working	Likert Scale
	How are you coping with the current pandemic situation? What are your coping strategies, if any?	Open-ended question

Table 1: Questionnaire for Academics at the Faculty of Dental Surgery

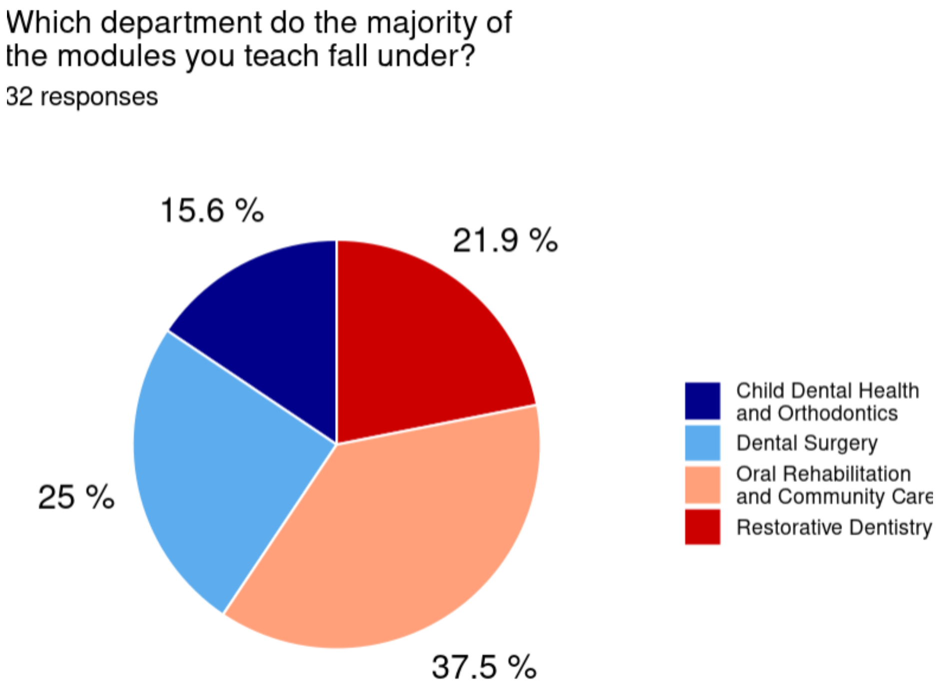

Figure 1: Distribution of participating academics within different departments in the Faculty of Dental Surgery, University of Malta.

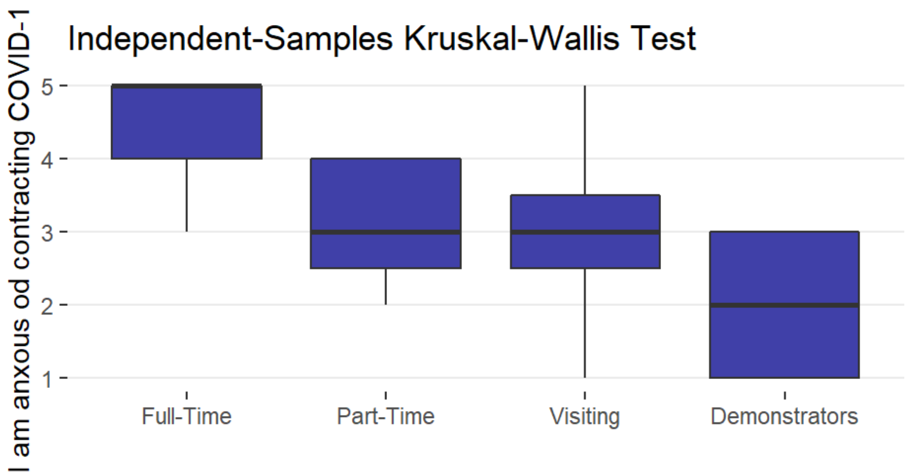

Figure 2: Comparison between different faculty members with different academic appointments regarding anxiety of contracting COVID-19 ($P = 0.020$).

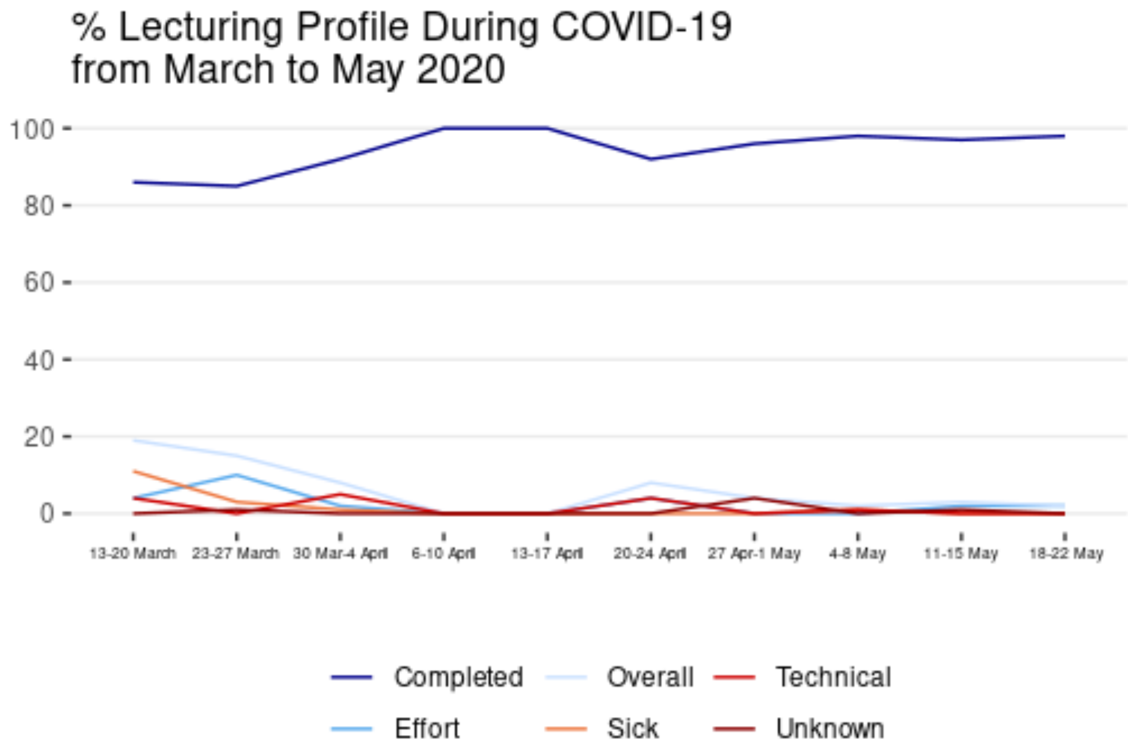

Figure 3: Lecturing profile during the pandemic.

Camilleri, L. et al. (2022). *Xjenza Online*, 10(1): 23–29.

Xjenza Online: Science Journal of the Malta Chamber of Scientists
www.xjenza.org
DOI: 10.7423/XJENZA.2022.1.03

Research Article

Identifying Risk Factors of Aortic Valve Replacement Using Frailty Models

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Abstract. Traditional survival modeling techniques, including the Kaplan Meier estimator, Cox regression and parametric survival models assume a fairly homogeneous population, where variation in survival durations can be explained by a small number of observed explanatory variables. However, in the presence of heterogeneity, frailty models are more appropriate to model survival data by introducing random effects that account for the variability generated from unobserved covariates. This paper presents two types of frailty models. The unshared frailty model assumes that different individuals have distinct frailties, while the shared frailty model assumes that the population can be divided into clusters, where members in the same cluster share the same frailty. Due to their nice mathematical properties, the Gamma and the Inverse Gaussian distributions are the most popular choices for the frailty distribution.
These survival models are fitted to a data set using the facilities of STATA. The participants are patients who underwent an aortic valve replacement procedure at a Maltese hospital between 2003 and 2019. The dependent variable is the duration till death or till censored and the eleven predictors provide information about the patients' health condition; surgery operative procedures; and duration of convalesce period. Moreover, in shared frailty models the patients are clustered by their diabetic condition since it is known that diabetic patients are more at risk of dying following aortic surgery.

Keywords: Shared and Unshared Frailty models, Gamma and Inverse Gaussian Distributions, Aortic Valve Replacement

1 Introduction

Survival analysis is a useful statistical tool for problems that deal with survival data, where the outcome variable is the duration for a certain event to occur. Initially survival analysis was used to model survival durations of patients undergoing surgical treatment or rehabilitation therapy; however, this statistical procedure has been extended to several research areas in the last three decades. Survival models are used to estimate the duration till failure of mechanical and electrical devices in engineering, relapse duration to alcohol and drug addiction in criminology. These models are used to evaluate product reliability in market research, measure viability of therapies, instruments and techniques in medicine, estimate life expectancy in demography, model marriage durations before separation/divorce in sociology, evaluate profitability of investment schemes in finance, amongst other applications.

The non-parametric Kaplan-Meier and Nelson-Aalen estimators, the semi-parametric Cox regression models, and the parametric survival models all assume that the members within a population are homogeneous with similar hazards. It is known in survival data, that unobserved heterogeneity exists between members, which cannot be explained directly by observable covariates. This unexplained variability is very common in epidemiological, medical and rehabilitation applications. For example, a specific treatment can have diverse effect on the recovery duration of patients, and a rehabilitation programme can have different impact on the relapse duration of drug abusers. To address this limitation, Vaupel et al. (1979) introduced frailty survival models, where a random effect (frailty) is introduced in the model to have a multiplicative effect on the hazard function of an individual or group of individuals. Frailty models allowed analysts to

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account for unobserved heterogeneity, which effectively reduces the possibility of inaccurate parameter estimates and biased standard errors. These models assume that the weaker individuals are more likely to succumb earlier than the stronger members. The univariate frailty model proposed by Vaupel et al. (1979) was further extended by Clayton (1978) who applied the technique on multivariate data related to chronic disease incidence in families.

Two popular frailty distributions in survival models are the Gamma and Inverse Gaussian distributions due their simpler mathematical properties. Hougaard (1984) showed that for a Gamma frailty distribution the relative heterogeneity remains constant, while the inverse Gaussian frailty assumes that this heterogeneity decreases with time. Both Vaupel et al. (1979) and Hougaard (1986) showed that although different individuals may have similar physical health conditions, some may be more susceptible to different threats and frailties. Hougaard (1986) argued that the choice between using an Inverse Gaussian or a Gamma distributed frailty depends entirely on the frailty instability of an individual. While frailty tends to be steady during an individual's life, it tends to deteriorate in later stages. Subsequently, many authors endorsed this frailty concept of a concealed random effect when analyzing survival data.

One of the objectives of frailty survival models is to estimate the variance of unobserved risk among different individuals. There are two approaches how frailty is distributed in the data by using shared and unshared frailty models. Unshared frailty models assume that different individuals have distinct frailties. For example, the recurrence times of machine malfunctions after being fixed is investigated by using unshared frailty models. On the other hand, shared frailty models assume that individuals within a group share frailty; however, this frailty may vary between groups. For example, some individuals may be more susceptible than others to be diagnosed with cancer or heart disease because of some unknown genetic condition, or some countries are more likely to engage in war than others for unknown reasons.

When intragroup correlation exists, shared frailty models may be more appealing than unshared frailty models. The seminal contributions of Clayton (1978) and Clayton et al. (1985) were fundamental in the development of shared frailty models. Identifiability issues related to frailty survival models were first addressed by Elbers et al. (1982), while theoretical proofs were given by Heckman et al. (1984). Other extensions focused on methods of how to measure correlation in bivariate survival data using an arbitrary parametric hazard function. Hougaard (1986) assumed Weibull individual hazards when fitting shared frailty models, while Whitmore et al. (1991) applied an inverse Gaussian shared frailty model by assuming constant individual hazards.

2 Theory of Unshared Frailty Models

The seminal work of Clayton et al. (1985), among other authors, highlighted the utility of frailty models and stressed the benefit of adding frailty to account for unobserved heterogeneity. As described in the introduction, there are two types of frailty models to analyze survival data in the presence of unobserved heterogeneity. In unshared frailty models, the frailty is introduced at the observation level as an unobservable multiplicative effect, on the baseline hazard function $h_0(t)$, given by:

$$h(t|\alpha) = \alpha h_0(t) \tag{1}$$

In this context, α is a non-negative random mixture variable where $E(\alpha) = 1$ and $\text{var}(\alpha) = \sigma^2$. When σ^2 is small, the values of α are located close to 1; however the values of α are more dispersed when σ^2 is large, inducing larger heterogeneity in the individual hazards $\alpha h_0(t)$.

Let $S(t|a)$ denote the survival function of a life conditional on the frailty α and let $\int_0^t h_0(s)ds = M_0(t)$ then

$$S(t|\alpha) = e^{-\int_0^t h(s|\alpha)ds} = e^{-\alpha \int_0^t h_0(s)ds} = e^{-\alpha M_0(t)} \tag{2}$$

If observed covariates, denoted by an *(p x n)* matrix $\mathbf{X}$, are available then the hazard is proportional to the baseline hazard. Moreover, the constant of proportionality is the term $\exp(\boldsymbol{\beta}'\mathbf{X})$, where $\mathbf{X} = (\mathbf{x}_1, ..., \mathbf{x}_p)$ and $\boldsymbol{\beta} = (\beta_1, ..., \beta_p)$ is the vector of regression parameters. So model (1) becomes:

$$h(t|\mathbf{X}, \alpha) = \alpha h_0(t) \exp(\boldsymbol{\beta}'\boldsymbol{X}) \tag{3}$$

The two distributions that are normally used for the probability density function $f(\alpha)$, of α are the gamma and inverse Gaussian distributions.

Given the simple Laplace transform of the Gamma distribution $\Gamma(\kappa, \lambda)$, it is easy to derive the closed-form expressions of the survival and hazard functions. The exponential distribution is a special case of the Gamma distribution when the shape parameter $\kappa = 1$. If α has a Gamma distribution and $\alpha > 0$, $\lambda > 0$, $\kappa > 0$ its probability density function is given by:

$$f(\alpha) = \frac{\lambda^\kappa}{\Gamma(\kappa)} \alpha^{\kappa-1} e^{-\lambda\alpha} \tag{4}$$

By setting $\kappa = \lambda = 1/\sigma^2$ ensures that the model is identifiable and $E(\alpha) = 1$ and $\text{var}(\alpha) = \sigma^2$. Using Laplace transform, Wienke (2010) derives the unconditional survival and hazard functions, which are given by:

$$S(t) = \mathbf{L}[M_0(t)] = \frac{1}{[1+\sigma^2 M_0(t)]^{1/\sigma^2}} \tag{5}$$

$$h(t) = -h_0(t)\frac{\mathbf{L}[M_0(t)]}{\mathbf{L}'[M_0(t)]} = \frac{h_0(t)}{1+\sigma^2 M_0(t)} \tag{6}$$

Moreover, Wienke (2010) shows that if observed covariates $\mathbf{x}_i$ are available for life i then the mean frailty and frailty variance for a life dying beyond time t are given by:

$$E(\alpha|\mathbf{X}, T > t) = \frac{1}{1+\sigma^2 M_0(t)\exp(\boldsymbol{\beta}'\boldsymbol{X})} \tag{7}$$

$$\text{var}(\alpha|\mathbf{X}, T > t) = \frac{\sigma^2}{[1+\sigma^2 M_0(t)\exp(\boldsymbol{\beta}'\boldsymbol{X})]^2} \tag{8}$$

The Inverse Gaussian distribution is also considered as a frailty distribution because similar to the Gamma distribution, simple closed-form expressions exist for the unconditional survival and hazard functions. If α has an Inverse Gaussian distribution and $\alpha > 0$, $\lambda > 0$, $\mu > 0$ its probability density function is given by:

$$f(\alpha) = \frac{\sqrt{\lambda}}{\sqrt{2\pi\alpha^3}}\exp\left[-\frac{\lambda(\alpha-\mu)^2}{2\mu^2\alpha}\right] \tag{9}$$

Setting $\mu = 1$ and $\lambda = 1/\sigma^2$ ensures that the model is identifiable, where $E(\alpha) = 1$ and $\text{var}(\alpha) = \sigma^2$. The unconditional density function, the unconditional survival and hazard functions are given by:

$$S(t) = \exp\left(\frac{1-\sqrt{1+2\sigma^2 M_0(t)}}{\sigma^2}\right) \tag{10}$$

$$h(t) = \frac{h_0(t)}{\sqrt{1+2\sigma^2 M_0(t)}} \tag{11}$$

If observed covariates $\mathbf{x}_i$ are available for life i then the mean frailty and frailty variance for a life dying beyond time t are given by:

$$E(\alpha|\mathbf{X}, T > t) = \frac{1}{\sqrt{1+\sigma^2 M_0(t)\exp(\boldsymbol{\beta}'\mathbf{X})}} \tag{12}$$

$$\text{var}(\alpha|\mathbf{X}, T > t) = \frac{\sigma^2}{[1+\sigma^2 M_0(t)\exp(\boldsymbol{\beta}'\mathbf{X})]^2} \tag{13}$$

3 Theory of Shared frailty Models

A generalization of the unshared frailty model is the shared frailty model, where the frailty is assumed to be group-specific. Basically shared frailty arises when the heterogeneity impact is common among individuals within a group, yet each set has a distinct random effect, which in turn causes frailties to be interrelated.

Suppose there exist n groups and that group i comprises n_i observations associated with the unobserved frailty α_i for $1 \le i \le n$. Their hazard functions are given by:

$$h(t|\alpha_i) = \alpha_i h_0(t) \tag{14}$$

Let $S(t|\alpha_i)$ denote the survival function of a life conditional on the frailty α_i and let $\int_0^{t_{ij}} h_0(s)ds = M_0(t_{ij})$ then

$$S(t_{i1}, ..., t_{in_i}|\alpha_i) = \exp[-\alpha_i \sum_{j=1}^{n_j} M_0(t_{ij})] \tag{15}$$

If observed covariates $\mathbf{X}_i$ for $1 \le i \le n$ are available then the hazard is proportional to the baseline hazard, where the constant of proportionality is the exponential term $\exp(\boldsymbol{\beta}'\mathbf{X})$. Assuming that the survival times in group i are independent, then model (16) becomes:

$$h(t|\mathbf{X}_i, \alpha_i) = \alpha_i h_0(t)\exp(\boldsymbol{\beta}'\mathbf{X}_i) \tag{16}$$

where $\boldsymbol{\beta} = (\beta_1, ..., \beta_p)$ is the vector of regression parameters and $\mathbf{X}_i = (\mathbf{x}_{i1}, ..., \mathbf{x}_{in_i})$ is the covariate matrix of the members in the i^{th} cluster. The conditional survival function on frailty α_i which is shared by all individuals in group i is given by:

$$S(t_{i1}, ..., t_{in_i}|\mathbf{X}_i, \alpha_i) = \exp\left[-\alpha_i \sum_{j=1}^{n_i} M_0(t_{ij})e^{\boldsymbol{\beta}'\mathbf{x}_{ij}}\right] \tag{17}$$

where $M_0(t_{ij})$ is the cumulative baseline hazard function of the j^{th} members in the i^{th} cluster. Averaging (17) with respect to the frailty α_i gives the survival function for the i^{th} cluster,

$$S(t_{i1}, ..., t_{in_i}|\mathbf{X}_i) = \mathbf{L}\left(\sum_{j=1}^{n_i} M_0(t_{ij}\right) e^{\boldsymbol{\beta}'\mathbf{x}_{ij}}) \tag{18}$$

where $\mathbf{L}$ denotes the Laplace transform of the frailty variable. The univariate unconditional survival function can be expressed by means of the Laplace transform:

$$S(t_{ij}|\mathbf{X}_i) = \mathbf{L}(M_0(t_{ij})e^{\boldsymbol{\beta}'\mathbf{x}_{ij}}) \tag{19}$$

$$M_0(t_{ij})e^{\boldsymbol{\beta}'\mathbf{x}_{ij}} = \mathbf{L}^{-1}[S(t_{ij}|\mathbf{X}_{ij})] \tag{20}$$

where $\mathbf{L}^{-1}$ is the inverse of the Laplace transform $\mathbf{L}$.
The Gamma and Inverse Gaussian frailty models are often used mainly for their nice properties, particularly their

simple Laplace transform. Assuming a Gamma frailty distribution with $E(\alpha) = 1$ and $\text{var}(\alpha) = \sigma^2$, the survival function for the i^{th} cluster is obtained by substituting (5) in (18).

$$S(t_{j1}, ..., t_{in_i}|\mathbf{X}_i) = \left(1 + \sigma^2 \sum_{j=1}^{n_i} M_0(t_{ij}) e^{\boldsymbol{\beta}' \mathbf{x}_{ij}}\right)^{-1/\sigma^2} \tag{21}$$

Moreover, by assuming an inverse Gaussian frailty distribution with $E(\alpha) = 1$ and $\text{var}(\alpha) = \sigma^2$, the survival function for the i^{th} cluster is obtained by substituting (10) in (18).

$$S(t_{i1}, ..., tin_i|\mathbf{X}_i) = \exp\left(\frac{1 - \sqrt{1 + 2\sigma^2 M_0(t) e^{\boldsymbol{\beta}' \mathbf{x}_{ij}}}}{\sigma^2}\right) \tag{22}$$

Popular choices for the baseline hazard include the exponential distribution for constant hazard; the Lognormal and Loglogistic distributions for humped hazards and the Weibull and Gompertz distributions for monotonic increasing hazards.

4 Application

The dataset consists of 480 patients who underwent an aortic valve replacement at the cardiothoracic centre in a Maltese hospital. This data was collected by a cardio-vascular surgeon over a period of 16 years, ranging between 2003 and 2019. Patients who had missing information were excluded from the dataset. Most of the patients who underwent this treatment were aged over 60 years, which is expected since the prevalence of heart disease increases drastically with age. After surgery, all patients had follow-up appointments. The time of death of patients who died before the end of the investigation period (2019) was recorded and the survival duration was computed. Patients who were still alive after the end of the investigation period were right censored.

The dataset includes a number of patient-related explanatory variables, together with other information related to the patients' health conditions in pre-operative and the post-operative periods. In this study, the dependent variable is *Time*, which measures the survival duration between the surgery and the time of death/end of the investigation period. *Status* indicates whether the patient is dead or alive at the end of the investigation period and will be used as a censoring variable. *BMI* provides the ratio of the patient's weight (kilograms) to the patient's height squared (m^2). The *Parsonnet* score measures the risk of death of a patient after undergoing heart surgery, where the larger the score the higher is the risk. *HDU* and *ITU* record the duration (days) of the patient's recovery in the High Dependency Unit and the Intensive Therapy Unit respectively. *Hypertension* indicates the patient's presence or absence of high blood pressure and *Transfusion* indicates whether the patient required/not required blood transfusion directly from another individual. *Ventilation* measures the duration (hours) that the patient spent on a life-assisting mechanical ventilator following the surgery. *Creatinine* indicates the presence/absence of waste product in the blood that normally passes through the kidneys and is eliminated through urine. *Dialysis* indicates whether or not the patient has kidney problems and is receiving dialysis treatment. *Blood* measures the blood volume (millilitres) that was provided to the patient during or after surgery and *IABP* indicates whether or not the patient required an intra-aortic balloon pump during heart surgery. *Diabetes* indicates whether the patient is diabetic or normal and will be used as a clustering variable in shared frailty models.

Of the 480 patients participating in the study, 22.8% died before the end of the investigation period and the rest were right censored. The mean Parsonnet score (6.24) indicates that the risk of mortality is fair and that there is a 5% predicted mortality rate. All the patients undergoing heart surgery spend one night in ITU and are retained in this unit if health condition is critical. If the patients' health condition is not life-threatening, they are transferred to the HDU for a convalescence period. The mean duration of patients requiring support of a ventilator was 5.24 hours and the mean blood volume transfused was 565.66 millilitres; however, these values were considerably larger for high risk patients. The mean BMI (29.44 kg/m^2) is larger than average indicating that the majority of the patients were overweight or obese. 29.7% of the patients were diabetic; 50.9% suffered from high blood pressure; 1.7% were on dialysis, 2.6% required the use of an intra-aortic balloon pump during surgery; 35% required blood transfusion and 3.2% of the patients had high levels of creatinine.

5 Results

It is known that the Gompertz distribution provides a remarkable close fit to adult mortality in contemporary developed countries. For this reason, all fitted models were implemented assuming a Gompertz baseline hazard function given by:

$$h_0(t) = \lambda_j e^{\gamma t_j} \tag{23}$$

where $\lambda_j = \exp(\beta_0 + ... + \beta_p x_p)$ and $\gamma$is an ancillary parameter. Table 1 displays the hazard ratios, standard errors and p-values of the non-frailty model. Since a number of the predictors were not significant, a backward procedure was used to identify the parsimonious model.

Parameter	H.R	S.E	Z	P> |z|
Constant	0.000	0.000	-24.4	0.000
BMI	1.005	0.012	0.42	0.675
Hypertension	0.865	0.158	-0.79	0.428
Parsonnet	1.096	0.010	9.57	0.000
ITU	0.799	0.152	-1.17	0.241
HDU	1.056	0.012	4.81	0.000
Ventilation	0.995	0.011	-0.46	0.647
Blood	0.999	0.001	-0.09	0.924
IABP	1.423	0.489	1.03	0.305
Dialysis	3.523	1.410	3.15	0.002
Creatinie	1.539	0.411	1.62	0.106
Transfusion	0.978	0.317	-0.16	0.874
Υ	0.000	0.000	9.47	0.000
Log-Likelihood				-914.31

Table 1: Non-frailty model

Table 2 displays the hazard ratios, standard errors and *p*-values of the parsimonious non-frailty model. This survival model assuming a Gompertz baseline hazard function identifies three significant predictors of survival duration, where the Parsonnet score is the best predictor, followed by recovery duration in HDU and dialysis treatment. The hazard of death for patients on dialysis is 2.878 times than those who have no kidney problems. Moreover, for every additional treatment day in the High Dependency Unit, the hazard of death increases by 4.9% and for every 1 unit increase in the Parsonnet score the risk of death increases by 9.1%, given that other effects are kept constant.

Parameter	H.R	S.E	Z	P> |z|
Constant	0.000	0.000	-75.45	0.000
Parsonnet	1.091	0.010	9.49	0.000
HDU	1.049	0.010	5.00	0.000
Dialysis	2.878	1.108	2.75	0.006
Υ	0.000	0.000	10.19	0.000
Log-Lokelihood				-919.40

Table 2: Parsimonious non-frailty model

Table 3 and table 4 display the hazard ratios and corresponding standard errors of the parsimonious unshared frailty models assuming a Gamma and Inverse Gaussian distribution and a Gompertz baseline hazard function. The likelihood ratio statistics (3.72 and 2.91) yield p-values (0.027 and 0.044), which are less than the 0.05 level of significance. This implies that the frailty variance is significantly positive.

Parameter	H.R	S.E	Z	P> |z|
Constant	0.000	0.000	-51.07	0.000
Parsonnet	1.113	0.018	6.68	0.000
HDU	1.060	0.013	4.84	0.000
Dialysis	3.346	1.704	2.37	0.018
Υ	0.000	0.000	6.47	0.000
Log-Lokelihood				-917.54

Table 3: Parsimonious unshared Gamma frailty model
LR test of $\sigma^2 \text{var}(\alpha) = 0$: Chibar2(01) = 3.72, p = 0.027

Parameter	H.R	S.E	Z	P> |z|
Constant	0.000	0.000	-50.16	0.000
Parsonnet	1.111	0.019	6.06	0.000
HDU	1.059	0.013	4.84	0.000
Dialysis	3.347	1.660	2.44	0.015
Υ	0.000	0.000	5.33	0.000
Log-Lokelihood				-917.95

Table 4: Parsimonious unshared Inverse Gaussian frailty model
LR test of $\sigma^2 \text{var}(\alpha) = 0:$ Chibar2(01) = 2.91, p = 0.044

Table 4 and table 5 display the hazard ratios and corresponding standard errors of the parsimonious shared frailty models assuming a Gamma and Inverse Gaussian distribution and a Gompertz baseline hazard function. The likelihood ratio statistics (approx. 0) yield p-values (approx. 1), which exceed the 0.05 level of significance. This implies that frailty vanishes completely when the patients are grouped by their diabetic condition.

Parameter	H.R	S.E	Z	P> |z|
Constant	0.000	0.000	-75.45	0.000
Parsonnet	1.091	0.010	9.49	0.000
HDU	1.049	0.010	5.0	0.000
Dialysis	2.879	1.108	2.75	0.006
Υ	0.000	0.000	10.19	0.000
Log-Lokelihood				-919.40

Table 5: Parsimonious shared Gamma frailty model
LR test of $\sigma^2 \text{var}(\alpha) = 0:$ Chibar2(01) = 0.00, p = 1.000

Parameter	H.R	S.E	Z	P> |z|
Constant	0.000	0.000	-75.45	0.000
Parsonnet	1.091	0.010	9.49	0.000
HDU	1.049	0.010	5.0	0.000
Dialysis	2.879	1.107	2.75	0.006
Υ	0.000	0.000	10.19	0.000
Log-Lokelihood				-919.40

Table 6: Parsimonious shared Inverse Gamma frailty model
LR test of $\sigma^2\text{var}(\alpha) = 0$: Chibar2(01) = 0.00, p = 1.000

6 Conclusion and Recommendations

All five models identify three significant predictors and all models highlight that the hazard of death is higher for patients who are on dialysis and increases with an increase in the Parsonnet score and an increase in the treatment duration in HDU. Table 7 shows the AIC and BIC values of the five fitted models. The fact that these values vary marginally between the five model fits indicate, that for this data set, shared and unshared frailty models did not provide a considerably improvement in goodness of fit compared to non-frailty models. This is a clear example where a more complex model does not always provide more predictive power than a simpler model. However, addressing heterogeneity due to unobserved covariates is highly recommended to obtain robust estimates of the hazard ratios and standard errors.

Frailty Distribution	AIC	BIC
No frailty assumed	1848.8	1869.7
Unshared Gamma	1847.1	1872.1
Unshared Inverse Gaussian	1847.9	1872.9
Shared Gamma	1848.8	1875.8
Shared Inverse Gaussian	1848.8	1875.8

Table 7: AIC and BIC measures for goodness of fit

The Gamma and Inverse Gaussian distributions have been used extensively as frailty distributions, mainly because of their simple Laplace transform. Another suggestion is to use the log-normal distribution for frailty, particularly when the random effects are assumed to be normally distributed. This allows more flexibility especially in modelling multivariate correlation structures. The development of new statistical software in enhancing computational power and the development of user-friendly estimation procedures such as the MCMC adaptive quadrature techniques make it possible to accommodate normal distributed random effects.
Another recommendation is to use semi-parametric frailty models, which extends the proportional hazards Cox model by introducing random effects to account for unobserved heterogeneity in the data. This semi-parametric approach is available both for shared and unshared Gamma frailty. Two approaches can be used to estimate parameters in semi-parametric frailty models. The first approach is the EM algorithm, which iterates between the Expectation and the Maximization steps. The second approach is the penalized partial likelihood (PPL) method, where estimation is based on Laplace approximation of the likelihood function.
Another recommendation is to use accelerated failure time (AFT) survival models instead of proportional hazards (PH) models. AFT models assume that the effect of a covariate is to decelerate or accelerate the survival outcome by a constant. This differs from PH models which assume that the effect of a covariate multiplies the hazard by a constant. Survival distributions that accommodate AFT survival models in STATA are the Exponential, Weibull, Log-normal and Log-logistic distributions.
Another recommendation is to use correlated frailty models, which are mixture models that assume that the frailty for each individual is random. These models assume that event times in a cluster are independent, given the frailties of the individuals. In other words, frailty variables are allowed to be correlated but may not necessarily be common to all individuals in a cluster, implying dependence between event times. The shared frailty models are special cases of the correlated frailty models by setting the correlations between the frailties to be equal to 1.
Another recommendation is to use multilevel survival models. Traditional survival models assume that individuals are independent of each other. However, individuals who are nested within higher level structures are more likely to have correlated outcomes, thus violating the assumption of independence. The homogeneity within clusters may be caused by cluster characteristics that are difficult to measure, such as practices that vary between hospitals. However, through multilevel survival models it is possible to accommodate the multilevel structure while accounting for the grouping of lower level units within higher level units.
One final recommendation is to use Copula models to model clustered data; however a requirement for these models is that the sample size for each cluster is the same. Copula models are fitted by using a two-stage procedure. The marginal survival functions are estimated, in the first step, ignoring the groupings within the data. This can be carried out by using a parametric, semi-parametric or non-parametric approach. The copula parameters are then estimated in the second step. Alternatively, one can use a one-step procedure by maximizing the likelihood.

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Diacono, S. et al. (2022). *Xjenza Online*, 10(1): 30–36.

Xjenza Online: Science Journal of the Malta Chamber of Scientists
www.xjenza.org
DOI: 10.7423/XJENZA.2022.1.04

Research Article

Analysis on how COVID-19 is affecting health care workers

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Abstract. The COVID-19 pandemic has impacted most of the world's population, in this paper we are interested particularly in how it has impacted directly the healthcare workers and front-liners working in Malta. The questionnaire conducted focused on issues that impacted them directly and indirectly such as stress levels, work load, and their psychological well-being. Whilst it is evidence that during the pandemic, health care workers were faced with psychological challenges, health care professionals working in Malta still shy away from looking for help for various reasons such as lack of resources, lack of education and fear of stigma. Through this research, it seems that the way forward during these challenging times is to increase the support from government entities, to increase education and awareness regarding mental health and support.

Keywords: COVID-19, Healthcare Workers, Malta

1 Aim

The aim of our questionnaire is to look into how this pandemic has effected the health care workers, in terms of workload, stress and other concerns they might have. The response we have is mostly coming from nurses as well as a minor number coming from doctors, and other health care professionals.

2 Introduction

COVID-19 pandemic has led to the entire humanity worldwide to face a severe health care crisis. The World Health Organisation (WHO) defines a pandemic to be "an epidemic occurring worldwide, or over a very wide area, crossing international boundaries and usually affecting a large number of people." (Doshi, 2011) Yet it is not the first time that humanity has had to deal with a pandemic. Throughout this century many pandemics have emerged and have been tackled with including the Spanish Flu, Severe acute respiratory syndrome (SARS), Middle East respiratory syndrome (MERS), Ebola, Swine Flu. It is important to note how pandemics do not only cause increased physical illnesses and unfortunately increased mortality but it also leads to tremendous mental health problems including anxiety and depression in both the infected and non-infected. (Wiebers et al., 2020)

Throughout this pandemic we are continuously praising the work of our front-liners health care workers (HCW) who are playing a crucial role in providing care to the community. Working in such foreseen circumstances with a risk of contracting the virus, HCWs have a high prevalence of mental health problems including anxiety, depression, burnout, illness, anxiety and so on. In fact, numerous international literature and studies have evidenced how HCWs who are directly working with COVID-19 patients are not only at increased risk of contracting the virus but also at increased risk of developing mental health symptoms. It is very easy take for granted the mental health of HCWs since it is HCWs who deal with the community's mental health and hence it is often considered that they would be able to manage themselves well. The increasing number of confirmed positive cases, deaths, work burden, not enough personal protective equipment, lack of specific treatment, having to stay in quarantine, being away from their loved ones, risk of themselves of getting infected can all lead to a mental health burden to HCWs. In fact, studies and literature on the psychological impact of COVID-19 pandemic and previous pandemics on HCWs is still elusive. (Bai et al., 2004; Chan, 2003; Wong et al., 2005)

The current paper is aimed to evaluate the mental health effect of the HCWs during the COVID-19 pandemic, by quantifying the magnitude of their symptoms of depression, anxiety and analysing potential risk factors associ-

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ated with these symptoms.

3 Material and Methods

Study Setting: Ethical approval for the study was obtained from the local ethics committee of Pro Deo International, University and University of Catania. The study was conducted with the use of an anonymous questionnaire sent to Front Liners working in the Medical Aspect including doctors, nurses, carers, physiotherapists, pharmacists and all other workers who have worked or are still working in a hospital or clinical setting. Each medical front liner who works with the Government in Malta has a government email. Medical front liners were reached by an email through their government email. The collection period of questionnaire collection was from the beginning of August till the end of October. Obviously numerous health care professionals work in private setting in Malta and Gozo yet it was found to be virtually impossible to obtain the emails of all the health care professionals who work privately and hence in order to try to avoid bias it was concluded that questionnaires would only be sent to those who work with the Government of Malta. No other exclusion criteria were set.
Study Design: The study was a questionnaire-based analytical study to asses work stress during the pandemic using numerical scales where 1 referred to the least stress levels and 10 referred to the most stress levels that the individual is experiencing. Collection and analysis of data was carried out by a team composed of 4 people, who were previously trained on the content of the questionnaires. The data are grouped according to the questions posed and statistical processing is done with the program: Microsoft Word and Microsoft Excel. They are calculated by the following statistical analysis i.e., frequency, percentage and arithmetic mean. Presentation of data is done through tables and graphics.

4 Resultus

4.1 Demographic Data

In total 162 participants consented to participate in the questionnaire. The demographic data of the questionnaire participants is shown in figure 1. From these 162 participants, 22 were 25 years old or younger, 28 were 26-35 years of age, 37 were 36-45 years of age, 47 were 46-55 years of age while 28 were 56 years old and older. Therefore, it was concluded that most of our replies (29%) came from people between the age of 46 and 55 years and the age group with least response was that of 25 or younger (14%).

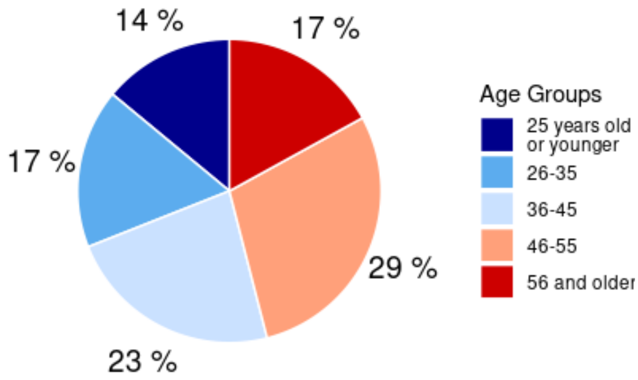

Figure 1: A Pie Chart showing the Demographic Data of the 162 health-care workers participants who consented to participate in the questionnaire.

Hospital-based “multidisciplinary teams” often involve all levels of “staff” on the treatment pyramid including aides, nurses, physician assistants, physical therapists, social workers, anaesthesiologists, and attending physicians. For the sake of this study, charge nurses, deputy nursing officers, health care worker, human resources, infection prevention and control. Medical lab scientist, medical representative, nurse administrator, nursing officer, senior nursing manager and senior ECG technician are considered as other professions for this study. Nurses, Doctors, Radiographers, Midwives, Occupational Therapists and Physiotherapists are considered as an individual entity. From the 162 participants, 128 identified as nurses, 7 as doctors, 5 as midwives, 7 as radiographers, 1 physiotherapist while 13 identified as other professions. Most of our participants came from nurses, contributing to 79% of our data, followed by other professions (8%), doctors and radiographers both contributing to 4% of our data. In turn followed by midwifes, contributing to 3% of our data and our least contributors came from occupational therapists, contributing to only 1% of our data. This data is collected in figure 2. In figure 3 the contribution of the specific professions who identified as other professions is also presented in the form of a bar chart.

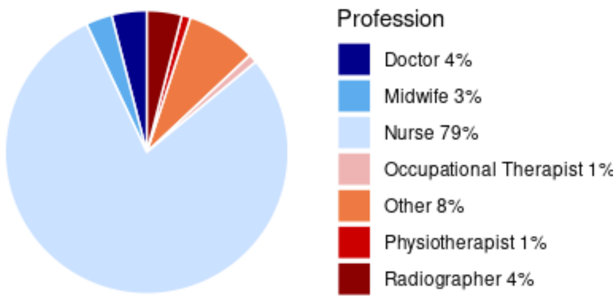

Figure 2: A Pie Chart showing the Profession of the 162 healthcare worker participants who consented to participate in the questionnaire.

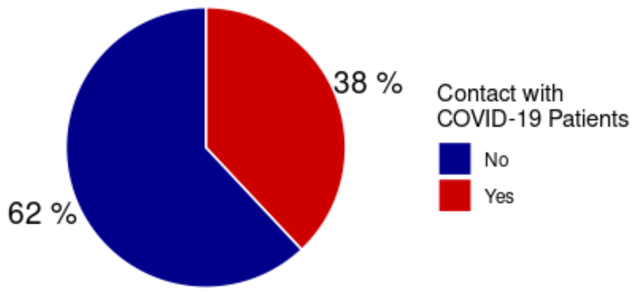

Figure 4: Health Care Workers Participants who reported that they work in direct or indirect contact with COVID-19 Patients.

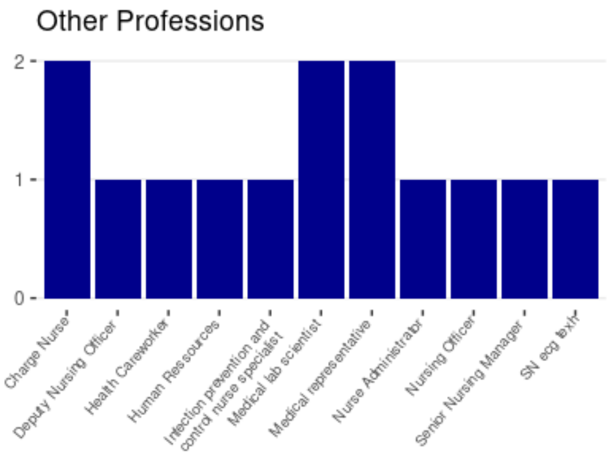

Figure 3: A Bar Chart showing the contribution of the specific professions who identified as other professions.

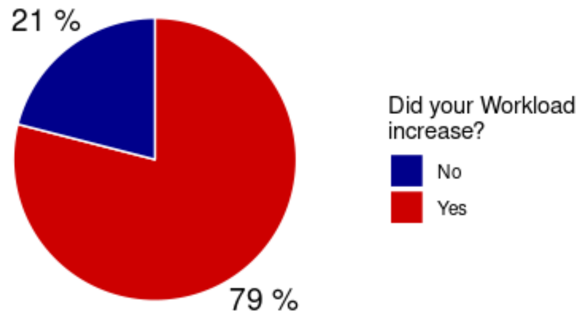

Figure 5: Pie chart showing Health Care Workers Participants who reported an increase or not an increase in Workload during the COVID-19 Pandemic.

4.2 Direct Contact with COVID-19 Patients

As seen in figure 4, 62 out of 162 said that they work directly with COVID-19 patients, however it is interesting to note from figure 5 that 128 participants reported an increase in workload. Therefore, the authors can presume that as a matter of fact this pandemic has resulted in an increase in workload in all Health Care Workers despite being directly or not directly involved with COVID-19 positive patients.

4.3 Stress Levels

As shown in figure 6, from the 162 participants, 142 have reported that they have felt that they are more stressed once the pandemic started, whilst only 20 participants have reported feeling that they have the same level of stress. One thing which the authors found interesting was that no participant has reported that they feel less stressed.

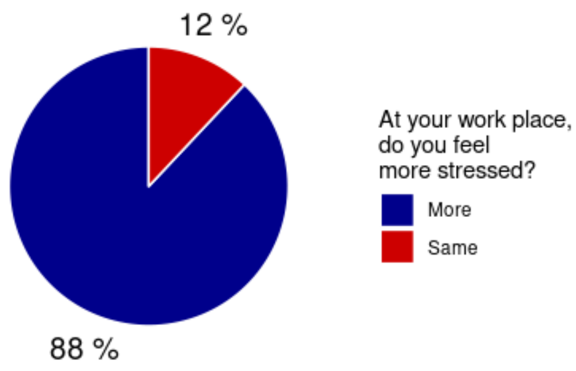

Figure 6: Health Care Workers Participants who reported the same amount or an increase in stress levels during the COVID-19 Pandemic.

As described above the stress scale used demonstrated the individual's self-reporting of stress from a scale of 1-10 with 1 being the least stressed and 10 being the most stressed. The stress scale and the number of people who corresponded to a specific stress scale is portrayed in figure 7. From figure 7 it can be noted how most of the participants, 52% reported a self-stress level of 8, while 29 participants contributing to 18% of the 162 participants reported a stress level of 10. As can be seen from the average of health care workers who have participated average stress level is 7.64 from 10. This is considered quite high. As will be shown below, the authors tried to deduce specific aspects which may have contributed to stress levels HCWs.

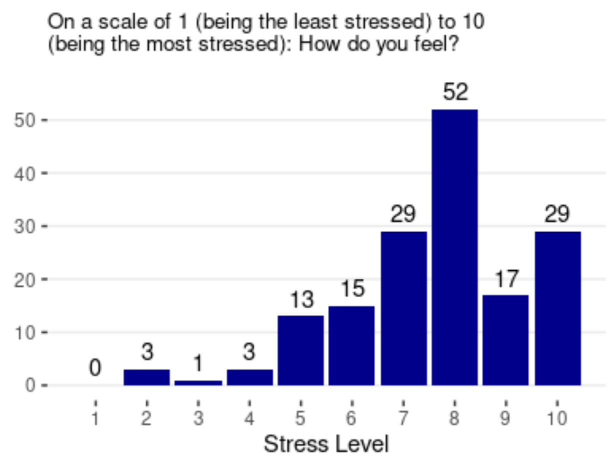

Figure 7: Stress scale and the number of people who corresponded to a specific stress.

4.4 Professional stressors in healthcare workers

As shown in figure 8, 134 of the participants feel that they are not receiving enough help in terms of their mental health. 45 said that they believe their concerns have a voice, whilst 117 believe their concerns do not have a voice. 54 of the participants feel well trained to face the pandemic whilst 108 do not. Of 162 participants 104 feel concerned about the currently available amount of personal protective equipment (PPEs). 141 still live with their relatives, whilst 21 had to move when the pandemic started due to fear of infection transmission. Of those who had to move, all but 2 answered that it had a huge impact on them. 134 did not feel the need to seek mental health help and 28 did or will be doing so. 149 participants feel like they were never trained for a pandemic, whilst 13 do.

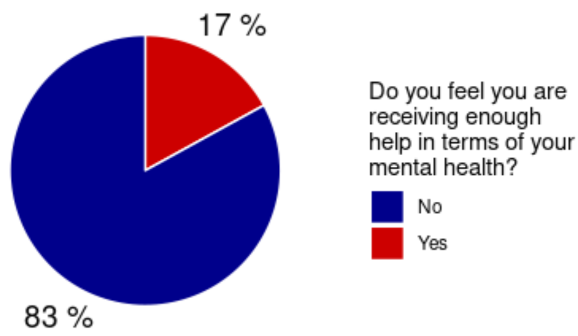

Figure 8: Pie chart showing Health Care Workers Participants feelings regarding whether they are receiving enough help for their mental health.

On the other hand, when participants were asked from a scale of 1-10 (1 being the least successful and 10 the most successful) of how the government was handling the situation in our country (table 1) and how the country's health sector is handling the situation (table 2) the results were mixed.

How well do you think your country's government is handling the situation?	Number of People
1	11
2	9
3	9
4	12
5	24
6	21
7	24
8	21
9	18
10	13

Table 1: Country's government situation and the number of people who corresponded

How well do you think your country's health sector is handling the situation?	Number of People
1	7
2	7
3	10
4	13
5	22
6	18
7	27
8	33
9	17
10	8

Table 2: Country's health sector handling of COVID-19 pandemic and the number of people who corresponded

It is also interesting to note how 87 of the participants have reported that they are feeling quite anxious and more anxious then normal while 75 of participants have reported to be a little more anxious than usual. When asked about what is worrying them the most, most have reported the following:

- Constant changes in contingency plan and protocols
- Getting sick with COVID-19 as well as long term complications
- Infecting family members especially vulnerable ones
- Lack of PPEs in certain wards
- Lack of proper education on doffing and donning
- Miscommunication between management and staff
- Staff shortage
- Lack of bubbles due to staff rotation
- Uncertainty and well as lack of education/information
- The longevity of the pandemic
- Burnout
- Lack of concern from the general public, false histories and those refusing to wear a mask
- Being away from relatives
- Solitude

5 Discussion

The COVID-19 pandemic has made a huge impact globally, it has effected every aspect of society, however this research main aim was evaluating how it has effected the health care workers in terms of workload, stress and what has been concerning them the most. This study was conducted with the aim to reach different health care professionals; most of the respondents were nurses. We have 96% of our participants from the Maltese Islands, whilst the other 4% are from Macedonia, Italy, Philippines and Pakistan. Less than half of the participants work directly in COVID-19 dedicated wards with COVID-19 positive patients, however the majority reported that their work load increased nonetheless. As expected the majority reported feeling more stressed than usual and none of our participants felt less stressed. What was found surprisingly worrying was the average stress level of 7.64, showing that stress levels within the health care community are quite extensive. Moreover, most of the participants believe they are not receiving enough help when it comes to their mental health. Lack of support from the system, the fear of being infected as well as transmission to family members were few of the concerns expressed which are increasing the stress levels in health care workers.

When asked what is worrying them the most, a trend can be established; the biggest concern was becoming infected as well as transmission to their families and the long term complications of this infection. Most were also worried about the establishment, as they expressed lack of communication as well as miscommunication, constant change in contingency plans and protocols, lack of necessary PPEs, lack of training in doffing and donning, and shortage of staff. Most felt unprepared and untrained with regards to a pandemic. Others had emotional concerns such as the longevity of the pandemic, fear of burnout, solitude and the lack of respect, co-operation and concern from the general public. Half of the participants also found themselves more anxious than usual.

It has already been shown that health care workers have a tendency for burnout, increased stresses and poor mental health states. The added pressures from the pandemic exacerbated these exponentially. Increased deaths within the hospital, increased demands and reduced control over the situation continues to put extensive pressure on health care professionals (Mehta et al., 2021). Through these results, a conclusion can be drawn that well-structured mental health care should be provided to these professionals; it should be an integral part of the profession and it should be person-centred (Eftekhar Ardebili et al., 2021). These trends are also present in other studies done outside the Maltese Islands on other health care workers, showing that it's a universal phenomenon. For example, studies done in Italy show the urgency for health care help provided in a structured and fast way to the health care workers. It has been suggested that programmes are implemented where medical professionals are assessed psychologically similar to the way they are assessed in terms of fitness to practice (Chirico et al., 2020).

Although the results showed this pandemic had a huge impact on health workers, it was surprising that most did not feel the need to seek mental health help. This could be due to fear of stigma within the work environment, lack of adequate help services, lack of time and the belief that one can handle the situation without external help.

Most health care workers in Malta feel that the government is handling the situation well but not good enough. The majority belief that our health sector is handling the pandemic well. This has to be viewed in the light of political affiliations within the Maltese Islands.

5.1 Study Limitations

At the time of conducting our questionnaire, we didn't feel the necessity to ask about gender because it doesn't change the final result we want to obtain from this study. However, it could have reflected differences in gender when it comes to mental health and stress related to work. We would have liked more participation from other countries, so as to compare, with the limited data we have we cannot make reliable comparisons.

6 Conclusion

The professional stress levels amongst healthcare workers were assessed by the numeric rating scale and it was found that more than half of them were stressed. There was no significant difference in stress levels between different grades of doctors and administrative staff. All workers in health care profession are equally stressed. The main occupational stressors were inability to finish work in available time, not having clarity about work, loss of interest, not being valued or rewarded for their work, frigid attitude of higher authorities. High stress levels in healthcare workers can lower the quality/efficiency in delivery of healthcare. Psychological stress was found to be related to respondents' perception of their own health and risk of being infected among both healthcare and frontline workers, but not among participants in the general public. This study provides useful information for policy decision makers with respect to the provision of supports to healthcare and frontline workers in the Maltese Islands experiencing the challenges of a pandemic.

6.1 Recommendations

There should be screening of stress incorporated during induction and training programmes. Individuals should be evaluated and counselled about psychological interventions of stress management. The Government should also take measures in regular trainings and assistance in terms of mental support program usage. The higher authorities should encourage the healthcare workers to make use of such programs. The health system should also make sure that the workers receive appreciation, recognition and rewards for their work which keeps them motivated at work.

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7 Appendix

7.1 Questionnaire used to carry out this study

Age	☐ 25 years old and younger	☐ 26-35	☐ 36-45	☐ 46-55	☐ 56 and older					
Nationality	_ _ _ _ _									
Country you currently work in	_ _ _ _ _									
Profession	☐ Dentist ☐ Physiotherapist	☐ Doctor ☐ Radiographer	☐ Midwife ☐ Speech language pathologist	☐ Nurse	☐ Occupational therapist ☐ Other					
If you chose Other to the above, please specify	_ _ _ _ _									
Are you in direct contact with COVID-19 patients?	☐ Yes	☐ No								
Did your workload increase?	☐ Yes	☐ No								
At your work place, do you feel…	☐ more stressed?	☐ the same?	☐ less?							
On a scale of 1 (being the least stressed) to 10 (being the most stressed) how do you feel?	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	☐ 8	☐ 9	☐ 10
Do you feel you are receiving enough help in terms of your mental health?	☐ Yes	☐ No								
Do you believe your concerns have a voice?	☐ Yes	☐ No								
Do you feel well trained to face a pandemic?	☐ Yes	☐ No								
Do you feel concerned about the currently available PPEs?	☐ Yes	☐ No								
What is currently worrying you the most? 1 sentence answer	_ _ _ _ _									
If you live with relatives, are you still living with them or did you have to move for their safety?	☐ Yes	☐ No								
If answer to above is no, do you feel that moving made a huge impact in your life?	☐ Yes	☐ No								
How well do you think your country's government is handling the situation?	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	☐ 8	☐ 9	☐ 10
How well do you think your country's health sector is handling the situation?	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	☐ 8	☐ 9	☐ 10
During these challenging times, did you seek help from a psychologist or a counselling service/do you plan to find help?	☐ Yes	☐ No								
With all this uncertainty do you find yourself being anxious/ more anxious than normal?	☐ Yes	☐ No								
Do you feel that during your professional training you were ever prepared for a pandemic scenario?	☐ Yes	☐ No								

Theuma, A. & Abela, K. (2022). *Xjenza Online*, 10(1): 37–47.

Xjenza Online: Science Journal of the Malta Chamber of Scientists
www.xjenza.org
DOI: 10.7423/XJENZA.2022.1.05

Research Article

Block Decomposition of Price Multipliers in a SAM Framework for Malta

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Abstract. A social accounting matrix can be utilised to model prices, providing a deeper understanding on price effects linked to intersectoral linkages, wages costs and cost-of-living adjustments. The objective of this article is to estimate price multipliers and their decomposition effects for the Maltese economy, based on the 2010 micro social accounting matrix. The estimated price multipliers follow the methodological framework proposed by Roland-Holst et al. (1995). The aim is to capture all existing price multiplier effects which are embedded within the entire circular flow of income and expenditure. This paper presents the first block decomposition of price multipliers locally with the objective to estimate and distinguish between transfer, open-loop and closed-loop effects. Therefore, this paper provides additional insight on tracing the different price effects following exogenous cost injections. Findings portray that the effects on production activities following injection in the same production account is dominated mainly by transfer effects. However, the price multiplier effects on endogenous accounts following an injection in production activities would result in mainly open-loop effects. The effects of higher wage costs on production activities and households are mainly dominated by open-loop effects, followed by induced effects. The estimated price multipliers can be utilised for policy formulation but are subject to the traditional input-output framework assumptions. However, the estimated price multipliers provide a first cut estimate of assessing price effects in terms of intermediary input costs, wages costs and cost-of-living adjustments following exogenous cost changes.

Keywords: Price Multipliers, Price Decomposition Effects, SAM-Price Model, Social Accounting Matrix.

1 Introduction

The objective of this study is to estimate the price multipliers for the Maltese economy based on the SAM framework. For the context of Malta, this is the first study that attempts to estimate price multipliers based on a Social Accounting Matrix (SAM). The estimated price multipliers follow the methodological framework proposed by Roland-Holst et al. (1995). Within the local context there had already been a study that introduced (Cassar, 2013) and applied (Theuma, 2018) the Leontief Price model. In the undergraduate dissertation by Theuma (2018), the author utilises a Symmetric input output table (SIOT) as the basis to simulate inter-sectoral price changes within the Maltese economy via the Leontief Price model[1]. The price effects coming from the additional production generated throughout the economy following the increased income that is originally triggered from greater household demand were not captured in Theuma (2018) since a SIOT was utilised for the basis of the model rather than a SAM. These missing links are referred to as closed-loop or induced effects.

Two years after the study by Theuma (2018), a 2010 Maltese SAM was constructed in the post-graduate dissertation by Theuma (2020), which shall be utilised as the basis for this paper. It was the study by Cassar (2013) that constructed the first reliable and coherent SAM for Malta for the year 2000. The SAM endogenising property allows price multipliers to take into account the closed-loop effects. Therefore, the results presented in this study extend the analysis to capture the price effects originating from the extra production coming from the additional income generated as a result of higher employment to satisfy the greater household demand. In terms of prices,

[1] In this study, prices refer to commodity prices, wage costs or cost-of-living effects.

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the multipliers estimated in this study capture the relationship between production activities, factors and institutions that cover the complete circular flow of income and expenditure of the Maltese economy. The estimated price multipliers effects are subject to exogenous shocks to any factor of primary inputs. Primary inputs consist of Gross Value Added (GVA), imports and net taxes on products. Also, GVA consists of compensation of employees, net operating turnover, sales of fixed capital and net taxes on production. Therefore, price fluctuations can be assessed with the estimated price multipliers following exogenous changes in any element of primary inputs.

A Symmetric Input-Output Table (SIOT) shows sectoral information regarding the production and consumption of an economy. The SIOT framework can be expanded to endogenise household behaviour, but it does not reflect the entire circular flow of income and expenditure of an economy. Models with households assumed as endogenous, such as the SAM, allow for the estimation of multipliers that capture the entire circular flow of income and expenditure (Miller et al., 2009). Therefore, a SIOT does not fully succeed in capturing the income effects distributed across institutions and factors. In this study, to capture the entire circular flow of income and expenditure a SAM for Malta is instead utilised. In matrix form, a SAM records the income generated by production activities, and the income distribution and redistribution between the various institutions within an economy (Round, 2003).

A SAM is also referred to as an economy-wide data framework (El-Said et al., 2001), which is considered as "comprehensive" (El-Said et al., 2001) and "flexible" (Round, 2003). The SAM framework retains a high degree of consistency because total receipts and payments throughout the economy balance. Within the SAM framework, receipts are displayed as row elements, while payments are portrayed as column elements. The flexibility of the SAM structure allows its accounts to be disaggregated according to the scope of study. A SAM can have different levels of disaggregation, such that economic activities can be analysed at a macro or micro level. A SAM with a single aggregated production account is referred to as a Macro SAM, which is mainly used to analyse an economy at a macro level, hence its name. On the other hand, when the production activities, factors and final demand are disaggregated at a sectoral level, it is generally referred to as a Micro SAM. As its name suggests, a Micro SAM is generally utilised to analyse the economy at a sectoral level. Other different SAM types also exist, such as household, financial or environmental-extended SAMs, which further disaggregate the Macro or Micro SAM accounts. The disaggregation level of the SAM accounts vary depending on the scope of study.

The next section provides an in-depth explanation of the methodology utilised to estimate the price multipliers and their decomposition. The Methodology Section starts off with a brief description of the data sources utilised to obtain the Micro SAM utilised for this study. It is then followed by an explanation on splitting the SAM accounts between endogenous and exogenous, which is later utilised as the basis to estimate and decompose the price multipliers for every Maltese economic sector. Two block-decomposition techniques shall be carried out, the multiplicative and the additive methods. The results are then put forward and discussed in section 3. The paper concludes with a summary of the main findings.

2 Data and Methodology

A SAM shall be utilised as the basis to estimate price multipliers and their decomposition effects to capture the entire circular flow of income and expenditure. In the postgraduate dissertation by Theuma (2020), the author had constructed a 2010 Micro SAM for Malta utilising reliable official statistical data sources. The Micro SAM also conforms to the latest European System of Accounts (Commission et al., 2013) framework and NACE (Eurostat, 2008) classification. The 2010 Maltese Micro SAM was readily available, disaggregated at a 44 sectoral level, with two factor accounts (labour and capital) and five institution accounts, of which three are considered as domestic, namely (i) Households, (ii) Government and (iii) Enterprises.

Subject to the traditional input-output framework and additional assumptions imposed during the SAM construction process[2], the comprehensive economy-wide data framework can be utilised to undertake multiplier analysis. In other words, the consequent effects of exogenous injections in an economy can be studied via multiplier or impact analysis. However, this requires a SAM to be partitioned into endogenous and exogenous accounts as shown in table 1. For consistency purposes, the same methodological structure put forward in Roland-Holst et al. (1995) is utilised. To capture the closed-loop or induced effects and obtain a complete set of price multipliers, production activities, factors, and households and enterprises institutions are taken as endogenous as portrayed in table 1. Government, taxes, capital and Rest of World accounts are taken as exogenous. The endogenous and exogenous partitioning structure adopted in this study also conforms to that adopted by Defourny et al. (1984), Pyatt et al. (1979) and Roland-Holst et al. (1995).

[2]Refer to Theuma (2020) for a detailed description of the additional assumptions imposed during the 2010 Maltese SAM construction process

It is worth noting that for the constructed 2010 Maltese SAM, the flows between the production activities and the enterprises institution are directly included under the production account rather than found separately within the enterprises institution column (Theuma, 2020). Therefore, payments by enterprises to production activities are assumed to be zero to avoid double counting. Also, the domestic household institution account also includes flows of Non-Profit Institutions Serving Households (NPISH).

From table 1, the flows amongst all endogenous accounts ($\mathbf{T}_{11}$, $\mathbf{T}_{13}$, $\mathbf{T}_{21}$, $\mathbf{T}_{32}$, $\mathbf{T}_{33}$) are portrayed as five separate block matrices, grouped into a single square (3×3) matrix. Block matrix $\mathbf{T}_{11}$ mirrors the intermediate consumption matrix that is readily found within a SIOT. Block matrix $\mathbf{T}_{13}$ denotes the expenditure of the endogenised domestic institutions on total output. Block matrix $\mathbf{T}_{21}$ denotes the value-added generated from factors by all production activities. Block matrix $\mathbf{T}_{32}$ denotes the income received by the endogenous domestic institutions for their labour services. Block matrix $\mathbf{T}_{33}$ denotes the flows between the endogenised domestic institutions. Block matrix $\mathbf{T}_{14}$ denotes final demand for all the exogenous accounts, which is identical to the final demand column found within a SIOT. Block matrix $\mathbf{T}_{24}$ denotes final demand for factors of production by exogenous accounts, which is required for output production. Block matrix $\mathbf{T}_{34}$ denotes the income received by all endogenised domestic institutions from all exogenous institutions. Similar to the injection column vector ($\mathbf{T}_{14}$, $\mathbf{T}_{24}$, $\mathbf{T}_{34}$), the leakages row vector ($\mathbf{T}_{41}$, $\mathbf{T}_{42}$, $\mathbf{T}_{43}$) denotes the flows from endogenous to exogenous accounts in the form imports, savings, and taxes, respectively. Block matrix $\mathbf{T}_{44}$ represents the inter-institutional transactions between all exogenous institutions. Total receipts and payments in table 1 must equate, such that every column element ($\mathbf{Y}_1$, $\mathbf{Y}_2$, $\mathbf{Y}_3$, $\mathbf{Y}_4$) and row element ($\mathbf{Y}_1$, $\mathbf{Y}_2$, $\mathbf{Y}_3$, $\mathbf{Y}_4$) within the SAM structure balance (Theuma, 2020). table 1 can also be portrayed in such a way to provide a picture of the entire circular flow of income and expenditure of an economy, as displayed in figure 1.

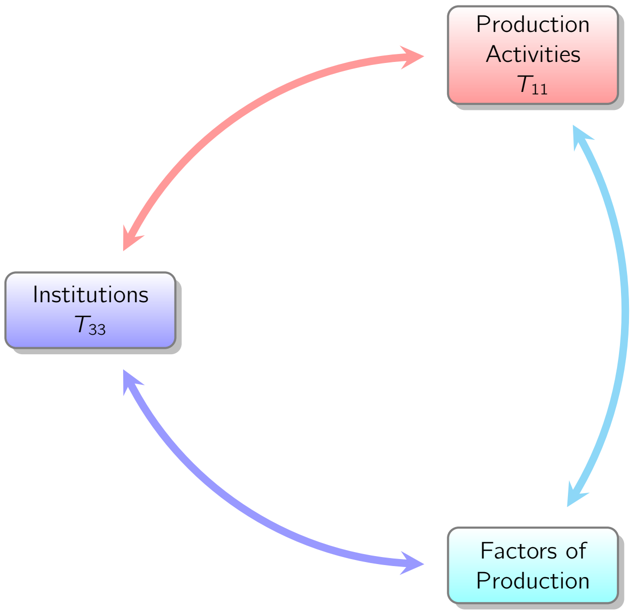

Figure 1: Circular Flow of Income and Expenditure

Source: (Defourny et al., 1984).

From figure 1, departing from block matrix $\mathbf{T}_{11}$, income is generated from the value-added taking place during the production processes of economic sectors. The newly generated income is then transformed into factors of production, which are supplied by the various institutions present in the economic system to produce goods and services. This process is visualised as $\mathbf{T}_{21}$ in table 1. Factors of production are then accrued to institutions, representing amongst others, the income distribution to households. Institutions can have transactions between themselves, $\mathbf{T}_{33}$, such as inter-income transfers between households. The income generated and distributed to households is then utilised for expenditure of goods and services by the various economic institutions $\mathbf{T}_{13}$ as portrayed in table 1. The cycle repeats itself portraying the movements and generation of income from producers to workers and back.

Utilising the partitioning structure of table 1, we can define matrix $\mathbf{A}$ that denotes the average expenditure propensities, representing the fixed interactions between the inputs and output of every sector. These sectoral fixed interactions are generally denoted as $\mathbf{a}_{ij}$, portraying the input $\mathbf{i}$ required by sector $\mathbf{j}$ to produce a unit of a commodity. Therefore, $\mathbf{a}_{ij}\mathbf{y}_j$ are required to produce $\mathbf{t}_{ij}$ number of goods. From table 1, in matrix algebra notation $\mathbf{a}_{ij}$ can be made subject of the formula to represent the technical coefficients matrix.

Partitions		**Endogenous**	**Endogenous**	**Endogenous**	**Exogenous**	**Total**
	SAM Accounts	Production Activities	Factors	Household and Enterprises	Government, Taxes, Capital and RoW	
Endogenous	Production Activities	T_{11}	0	T_{13}	T_{14}	Y_1
Endogenous	Factors	T_{21}	0	0	T_{24}	Y_2
Endogenous	Household and Enterprises	0	T_{32}	T_{33}	T_{34}	Y_3
Exogenous	Government, Taxes, Capital and RoW	T_{41}	T_{42}	T_{43}	T_{44}	Y_4
Total		Y_1	Y_2	Y_3	Y_4	

Table 1: SAM Framework's Schematic Structure

Source: (Roland-Holst et al., 1995).

$$\mathbf{T} = \mathbf{A}\widehat{\mathbf{Y}} \tag{1}$$

$$\mathbf{T}\widehat{\mathbf{Y}}^{-1} = \mathbf{A} \tag{2}$$

$$\frac{t_{ij}}{y_j} = a_{ij} \tag{3}$$

Where square matrix $\mathbf{A}$ is made up of only endogenous SAM accounts, square matrix $\mathbf{T}$ denotes the expenditure by the endogenous accounts and matrix $\widehat{\mathbf{Y}}$ denotes a square matrix with diagonal elements $\mathbf{y}_i$ $(i = 1, ..., n)$. The matrix of average expenditure propensities $\mathbf{A}$ utilised in this paper is an augmented version to that derived from a SIOT, since it now includes all flows of the endogenous accounts. Since matrix $\mathbf{A}$ is derived by dividing its internal five block matrices with their respective income total, it captures all the relationships between the endogenous accounts.

$$\mathbf{A} = \begin{bmatrix} \mathbf{A}_{11} & \mathbf{0} & \mathbf{A}_{13} \\ \mathbf{A}_{21} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{A}_{32} & \mathbf{A}_{33} \end{bmatrix} \tag{4}$$

Block matrix $\mathbf{A}_{11}$ denotes the share of intermediary inputs utilised during the production processes to produce output. Block matrix $\mathbf{A}_{21}$ denotes the share of factors required to produce a one-euro worth of output. Block matrix $\mathbf{A}_{13}$ denotes the mean purchases of every commodity supplied by the endogenous institutions for every one-euro worth of total expenditure. Block matrix $\mathbf{A}_{32}$ denotes the income received by the endogenous institutions for every one-euro worth of labour services carried out. Block matrix $\mathbf{A}_{33}$ denotes on average every one-euro worth of transfers between every endogenous institution (Cassar, 2013).

Following the endogenous and exogenous partitioning in table 1 and the standard Leontief demand-driven assumptions, the SAM-quantity model is derived next. In the SAM-quantity model, production is assumed to change while prices are assumed to remain unchanged. The justification of these assumptions come only in the presence of excess capacity and unlimited supply of resources (Roland-Holst et al., 1995). Utilising the partitioning structure derived in table 1 and Matrix $\mathbf{A}$ of average expenditure propensities, the SAM-quantity model can be utilised to derive income of group 1 by:

$$\begin{aligned} \mathbf{Y}_1 &= \mathbf{A}_{11}\mathbf{Y}_1 + \mathbf{A}_{13}\bar{\mathbf{Y}}_3 + \mathbf{A}_{14}\bar{\mathbf{Y}}_4 && (5) \\ &= (\mathbf{I} - \mathbf{A}_{11})^{-1}(\mathbf{A}_{13}\bar{\mathbf{Y}}_3 + \mathbf{A}_{14}\bar{\mathbf{Y}}_4) && (6) \\ &= \mathbf{M}_{11}\mathbf{x} && (7) \end{aligned}$$

Where $\mathbf{M}_{11} = (\mathbf{I} - \mathbf{A}_{11})^{-1}$ denotes the SAM Leontief inverse matrix that mirrors the SIOT Leontief inverse or multiplier matrix, matrix $\mathbf{A}_{11}$ mirrors the SIOT Leontief technical coefficients matrix $\mathbf{A}$, and $\mathbf{x}$ mirrors the SIOT exogenous final demand column vector for every economic sector. To distinguish between endogenous and exogenous elements, those elements with a bar represent the SAM accounts partitioned as exogenous, while those without represent the remaining endogenous accounts. Therefore, the consequent effects on endogenous production following a one euro change in exogenous activity can be assessed. This can also be expressed as $\mathbf{\Delta Y}_1 = \mathbf{M}_{11}\mathbf{\Delta x}$.

The SAM-Price model, which is dual to the SAM-quantity model can also be explored. The assumptions change, whereby prices are allowed to change, while quantities are assumed to remain fixed. Let $\mathbf{p}_i$ represent a price index for the production activities of group $\mathbf{i}$. Utilising the same endogenous and exogenous split between the SAM accounts denoted in table 1, the first column can be represented in matrix algebra form as:

$$\begin{aligned} \mathbf{p}_1' &= \mathbf{p}_1'\mathbf{A}_{11} + \bar{\mathbf{p}}_2'\mathbf{A}_{21} + \bar{\mathbf{p}}_4'\mathbf{A}_{41} && (8)\\ &= (\bar{\mathbf{p}}_2'\mathbf{A}_{21} + \bar{\mathbf{p}}_4'\mathbf{A}_{41})(\mathbf{I} - \mathbf{A}_{11})^{-1} && (9)\\ &= \mathbf{v}_1'\mathbf{M}_{11} && (10) \end{aligned}$$

Where $\mathbf{v}_1'$ denotes a row vector of exogenous costs, and $\mathbf{M}_{11}$ denotes the same Leontief inverse matrix found in the Leontief Demand-Driven model balance equation. Dual to the SAM-quantity model, the SAM-price model can be utilised to assess the effects of a one euro exogenous cost change on prices $\mathbf{\Delta p}_1' = \mathbf{\Delta v}_1'\mathbf{M}_{11}$. Utilising table 1, the above can be expanded to represent a set of linear equation in terms of prices.

$$\begin{aligned} \mathbf{p}_1' &= \mathbf{p}_1'\mathbf{A}_{11} + \mathbf{p}_2'\mathbf{A}_{21} + \bar{\mathbf{p}}_4'\mathbf{A}_{41} && (11)\\ \mathbf{p}_2' &= \mathbf{p}_3'\mathbf{A}_{32} + \bar{\mathbf{p}}_4'\mathbf{A}_{42} && (12)\\ \mathbf{p}_3' &= \mathbf{p}_1'\mathbf{A}_{13} + \mathbf{p}_3'\mathbf{A}_{33} + \bar{\mathbf{p}}_4'\mathbf{A}_{43} && (13) \end{aligned}$$

Let $\mathbf{p}'$ denote a row vector of prices $(\mathbf{p}_1', \mathbf{p}_2', \mathbf{p}_3')$ for the endogenous SAM accounts and $\mathbf{v}' = \mathbf{p}_4'\mathbf{A}_4$ denotes the row vector of exogenous costs, where $\mathbf{A}_4$ comprises of row elements $(\mathbf{A}_{41}, \mathbf{A}_{42}, \mathbf{A}_{43})$. The balance equation of the SAM-Price model is summarised as:

$$\mathbf{p}' = \mathbf{v}'(\mathbf{I} - \mathbf{A})^{-1} = \mathbf{v}'\mathbf{M} \tag{14}$$

Where $\mathbf{p}'$ is a row vector of unitary prices, $\mathbf{v}'$ is a row vector portraying the ratio of primary inputs expenditure required by each sector to produce one monetary unit worth of output $(\frac{v_n}{y_n})$ and $\mathbf{M}$ is a multiplier matrix which is common for the Leontief quantity and price models. However, the interpretation of the multiplier matrix is different between the two dual models. For the interpretation of the Leontief SAM-price model, the rows across matrix $\mathbf{M}$ are interpreted. For the Leontief SAM-quantity model or the SAM-based output (production) multipliers[3], the columns of matrix $\mathbf{M}$ are instead interpreted. To distinguish between the two possible interpretations of the multiplier matrix $\mathbf{M}$, its transpose $\mathbf{M}'$ will be referred to as the price transmission matrix.

Stone (1936) and Pyatt et al. (1979) introduce the multiplicative and additive block-decomposition methods to disaggrega te matrix $\mathbf{M}$ or $\mathbf{M}'$ into three separate block matrices which have important economic meaning[4]. The decomposition of the multiplier matrix allows for the interpretation of the (i) transfers, (ii) open-loop, and (iii) closed-loop matrices. The three respective block-matrices reflect the consequent effects on the endogenous partitioned group as shown in table 1 following an exogenous injection in the economic system. The multiplicative block-decomposition method shall be primarily carried out to estimate the three decomposition multiplier matrices (**M1**, **M2**, **M3**). The additive block-decomposition method is applied afterwards to be able and provide a clear interpretation of the three different price multiplier effects. The multiplicative block-decomposition method is presented next, which starts off from the SAM-Price model and the introduction of a new matrix $\widetilde{\mathbf{A}}$.

$$\widetilde{\mathbf{A}} = \begin{bmatrix} \mathbf{A}_{11} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{A}_{33} \end{bmatrix} \tag{15}$$

Matrix $\widetilde{\mathbf{A}}$ is a square matrix of average expenditure propensities, extracted directly from matrix $\mathbf{A}$. Matrix $\widetilde{\mathbf{A}}$ must satisfy the condition that $(\mathbf{I} - \widetilde{\mathbf{A}})$ is invertible (Roland-Holst et al., 1995).

[3]For the context of this paper, the SAM-based output (production) multipliers go beyond the scope of this study. However, a more detailed analysis on the output (production) multiplier for the Maltese economy can be found in Cassar (2013, 2015), Cassar et al. (2018) and Theuma (2020).

[4]The two block-decomposition methods applied in this paper follow the methodological framework proposed by Stone (1936) and Pyatt et al. (1979).

$$\mathbf{p}' = \mathbf{v}'\mathbf{M} \tag{16}$$
$$= \mathbf{p}'\mathbf{A} + \mathbf{v}' \tag{17}$$
$$= \mathbf{p}'\mathbf{A} + \mathbf{p}'\widetilde{\mathbf{A}} - \mathbf{p}'\widetilde{\mathbf{A}} + \mathbf{v}' \tag{18}$$
$$= \mathbf{p}'(\mathbf{A} - \widetilde{\mathbf{A}})(\mathbf{I} - \widetilde{\mathbf{A}})^{-1} + \mathbf{v}'(\mathbf{I} - \widetilde{\mathbf{A}})^{-1} \tag{19}$$
$$= \mathbf{p}'\mathbf{A}^* + \mathbf{v}'(\mathbf{I} - \widetilde{\mathbf{A}})^{-1} \tag{20}$$
$$= [\mathbf{p}'\mathbf{A}^* + \mathbf{v}'(\mathbf{I} - \widetilde{\mathbf{A}})^{-1}]\mathbf{A}^* + \mathbf{v}'(\mathbf{I} - \widetilde{\mathbf{A}})^{-1} \tag{21}$$
$$= \mathbf{p}'\mathbf{A}^{*2} + \mathbf{v}'(\mathbf{I} - \mathbf{A})^{-1}(\mathbf{I} + \mathbf{A}^*) \tag{22}$$
$$= [\mathbf{p}'\mathbf{A}^* + \mathbf{v}'(\mathbf{I} - \widetilde{\mathbf{A}})^{-1}]\mathbf{A}^{*2} + \mathbf{v}'(\mathbf{I} - \widetilde{\mathbf{A}})^{-1}(\mathbf{I} + \mathbf{A}^*) \tag{23}$$
$$= \mathbf{p}'\mathbf{A}^{*3} + \mathbf{v}'(\mathbf{I} - \widetilde{\mathbf{A}})^{-1}(\mathbf{I} + \mathbf{A}^* + \mathbf{A}^{*2}) \tag{24}$$
$$= \mathbf{v}'(\mathbf{I} - \widetilde{\mathbf{A}})^{-1}(\mathbf{I} + \mathbf{A}^* + \mathbf{A}^{*2})(\mathbf{I} - \mathbf{A}^{*3})^{-1} \tag{25}$$
$$= \mathbf{v}'\mathbf{M}_1\mathbf{M}_2\mathbf{M}_3 \tag{26}$$

Where $\mathbf{A}^* = (\mathbf{A} - \widetilde{\mathbf{A}})(\mathbf{I} - \widetilde{\mathbf{A}})^{-1}$ and the multiplication of $\mathbf{M}_1\mathbf{M}_2\mathbf{M}_3$ equates to the SAM Leontief multiplier matrix $\mathbf{M}$. By taking the transpose of the three block-multiplier decomposition matrices, a new equation is obtained that satisfies the price transmission matrix.

$$\mathbf{p} = \mathbf{M}'\mathbf{v} = \mathbf{M}_3'\mathbf{M}_2'\mathbf{M}_1'\mathbf{v} \tag{27}$$

Where:

$$\mathbf{M}_1' = \begin{bmatrix} (\mathbf{I} - \mathbf{A}_{11})^{-1} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{I} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & (\mathbf{I} - \mathbf{A}_{33})^{-1} \end{bmatrix} \tag{28}$$

$$\mathbf{M}_2' = \begin{bmatrix} \mathbf{I} & \mathbf{A}_{21}^* & \mathbf{A}_{32}^*\mathbf{A}_{21}^* \\ \mathbf{A}_{13}^*\mathbf{A}_{32}^* & \mathbf{I} & \mathbf{A}_{32}^* \\ \mathbf{A}_{13}^* & \mathbf{A}_{21}^*\mathbf{A}_{13}^* & \mathbf{I} \end{bmatrix} \tag{29}$$

$$\mathbf{M}_3' = \begin{bmatrix} (\mathbf{I} - \mathbf{A}_{13}^*\mathbf{A}_{32}^*\mathbf{A}_{21}^*)^{-1} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & (\mathbf{I} - \mathbf{A}_{21}^*\mathbf{A}_{13}^*\mathbf{A}_{32}^*)^{-1} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & (\mathbf{I} - \mathbf{A}_{32}^*\mathbf{A}_{21}^*\mathbf{A}_{13}^*)^{-1} \end{bmatrix} \tag{30}$$

Since the multiplier matrix $\mathbf{M}$ has been transposed to matrix $\mathbf{M}'$, the interpretation of the column and row elements of the SAM multiplier matrices ($\mathbf{M}, \mathbf{M}_1, \mathbf{M}_2, \mathbf{M}_3$) have also been switched. To analyse the price multiplier effects we now look down the columns of matrix $\mathbf{M}'$[5]. However, to obtain a more concise picture of the price multiplier decomposition effects, the Additive Block-Decomposition method is applied next.

$$\mathbf{M}' = \mathbf{I} + \mathbf{T} + \mathbf{O} + \mathbf{C} \tag{31}$$
$$= \mathbf{I} + (\mathbf{M}_1' - \mathbf{I}) + (\mathbf{M}_2' - \mathbf{I})\mathbf{M}_1' + (\mathbf{M}_3' - \mathbf{I})\mathbf{M}_2'\mathbf{M}_1' \tag{32}$$

[5]Refer to section 4 within the Appendix Chapter for Matrix M′.

Where $\mathbf{I}$ denotes the initial injection, $\mathbf{T} = (\mathbf{M}_1' - \mathbf{I})$ denotes the transfer effects, $\mathbf{O} = (\mathbf{M}_2' - \mathbf{I})\mathbf{M}_1'$ denotes the open-loop or cross multiplier effects and $\mathbf{C} = (\mathbf{M}_3' - \mathbf{I})\mathbf{M}_2'\mathbf{M}_1'$ denotes the closed-loop or induced effects. The Additive Block-Decomposition method enables us to provide a clearer interpretation of the price multiplier decomposition estimates, which is found in the next chapter. To apply the Additive Block-Decomposition method, the three decomposed multiplier matrices are required ($\mathbf{M}_1'$, $\mathbf{M}_2'$, $\mathbf{M}_3'$). Therefore, the Multiplicative Block-Decomposition matrix is applied before the Additive Block-Decomposition method because the former method is a requirement for the latter method.

3 Results and Discussion

The block-decomposition of the price multipliers enable us to examine the various effects of price changes into more detail. As shown in table 2, the decomposed price effects are namely (i) transfer effects, (ii) open-loop effects and (iii) closed-loop effects. The transfer effects portrayed in table 2 capture the price multiplier effects originating from direct links between the endogenous accounts and inter-sectoral transactions. From example 4 of table 2, the consequent impact of exogenously shocking the production cost of the Financial Services sector by one euro would result in a direct price increase of 0.01 euro in the same sector. The open-loop effects only capture the price multiplier effects coming from transfers between every endogenous account. From example 10 of table 2, the consequent impact of exogenously shocking the production cost of the Financial Services sector by one euro would result in an increase of 0.02 euro in wage costs. The closed-loop effects, also known as induced effects, capture the price multiplier effects originating from the additional production generated in the economy that ultimately comes from greater household demand. In other words, the closed-loop effects ensure a completed circular flow of income and expenditure throughout the economy as depicted in figure 1. Therefore, price multipliers capture the price effects that can be traced back to the "big circuits of influence" (Roland-Holst et al., 1995). From table 2, when the injected (origin) and influenced (destination) sectors are the same, a one is added as an initial injection[6] to reflect a one euro injection to the origin sector on the destination sector. Similarly, it is also possible to undertake a hypothetical scenario of any euro amount injected to any origin sector and assess the consequent price effects of any destination sector in the economy.

[6]The initial injection can also be thought of as an identity matrix with one on its diagonals embedded within the multiplier matrix M_1'.

Example	SAM Account Injection Origin	SAM Account influenced by the injection	Initial Injection (I)	Transfer Effects (T)	Open-Loop Effects (O)	Closed-Loop Effects (C)	Price Multipliers (M'_{ji})
1	Accommodation and Food Services	Travel Agency	0	0.08	0	0.03	0.11
2	Accommodation and Food Services	Accommodation and Food Services	1	0.01	0	0.04	1.05
3	Financial Services	Accommodation and Food Services	0	0.08	0	0.02	0.10
4	Financial Services	Financial Services	1	0.01	0	0	1.01
5	Financial Services	Advertising and Market Research	0	0.26	0	0.02	0.27
6	Electricity, Water and Waste Services	Textiles Manufacturing	0	0.19	0	0.02	0.22
7	Electricity, Water and Waste Services	Retail Trade	0	0.10	0	0.03	0.13
8	Financial Services	Endogenous Institutions	0	0	0.03	0	0.03
9	Accommodation and Food Services	Endogenous Institutions	0	0	0.05	0.01	0.06
10	Financial Services	Factors	0	0	0.02	0	0.03
11	Accommodation and Food Services	Factors	0	0	0.05	0.01	0.06
12	Factors	Activities of Households as Employers	0	0	0.99	0.17	1.16
13	Factors	Endogenous Institutions	0	0	0.16	0.03	0.19

Table 2: 2010 Price Multiplier Decomposition Effects for Malta

Source: Authors' Own Calculations.

Table 2[7] presents the price multipliers for domestic economic sectors, institutions, and factors. These price multipliers also include their block-decomposition effects. The Additive Block-Decomposition method is utilised to interpret and assess the results. As previously explained in the Methodology Chapter, the Multiplicative Block-Decomposition method was required to apply the Additive Block-Decomposition method. Generally, the results obtained from the Additive Block-Decomposition method are preferred for ease of interpretation. The results portrayed in table 2 were chosen to best explain the different kinds of multiplier decomposition effects that also exhibit important characteristics.

From table 2, examples 1 to 7 capture the decomposition effects of a one euro increase in exogenous costs of production activities, and the consequent influence on production prices. For instance, example 1 in table 2 portrays an approximate increase in production prices of around 0.11 euro for the Travel agency, Tour operator Reservation Service and Related Activities sector following a one euro exogenous increase in the cost of production activities originating from the Accommodation and Food Services sector. From the resulting 0.11 price multiplier increase, 0.08 euro increase takes the form of transfer effects and the remaining 0.03 euro increase take the form of closed-loop effects due to the additional production generated following the extra consumption of goods and services by households. In other words, the 0.08 euro increase in prices originates from the inter-sectoral transactions between production activities while the 0.03 euro increase in prices ultimately originates from additional household demand. In this case, the open-loop effects are zero because the origin and destination sectors belong to the same account category. In other words, the origin and destination sectors of examples 1 to 7 belong to the same production account.

From table 2, example 4 portrays that when the Financial Services sector is shocked by an initial injection (I) of one euro worth of exogenous cost, the price multiplier for that same sector amounts to 1.01 euro. Therefore, a one euro exogenous cost increase for the Financial Services sector would bring about an increase in production prices of that same sector by 1.01 euro, of which the majority is accounted by the injection itself, while a relatively small remaining effect of 0.01 euro takes the form of transfer effects. The low multiplier effects come from the Special Purpose Entities (SPEs) included in the Financial Services sector during the construction of the SIOT, which is conformant to the latest NACE Rev.2. However, since SPEs contain a substantial amount of import content, the level of leakages present in the domestic financial sector is high.

[7] In situations where the additive block-decomposition effects do not sum up to their respective price multiplier total, it is because of rounding up.

The inclusion of SPEs in the SAM reduces the magnitude of the multiplier effects attributed by the financial sector. The higher the share of leakages within the sector's production process relative to its domestic input requirements, the lower the effects of exogenous cost changes on prices would have.

Similarly, from table 2, example 5 denotes a price multiplier for the Advertising sector of 0.27 euro, of which approximately 96 per cent is attributable to transfer effects. For examples 1 to 7 it can be deduced that the price multipliers are dominated by transfer effects when compared to closed-loop effects. This implies that these sectors are highly integrated but exhibit weak forward linkages (Roland-Holst et al., 1995). Therefore, these estimates shed light on the underlying cost linkages between production activities.

Examples 8 and 9 present the price multiplier effects on endogenous institutions following a one euro exogenous cost increase in production activities. From table 2, example 8 portrays that the effects on the domestic households institution following a one euro exogenous cost in the Financial Services sector would result in a price multiplier effect of 0.03, which is entirely represented by open-loop effects. In example 9, a one euro exogenous injection in the Accommodation and Food Services sector would bring about a price multiplier effect of 0.06 euro on the households institution. From the 0.06 euro increase in the cost-of-living index, 0.05 takes the form of open-loop effects while the remaining 0.01 euro takes the form of closed-loop effects. Roland-Holst et al. (1995) stress that it is the tendency that for the households institution, open-loop effects dominate closed-loop effects, which is also the case for Malta as visualised in table 2. Compared to Examples 1 to 7, this time the origin and destination sectors belong to a different account category. As a result, the transfer effects are now zero for examples 8 and 9.

Examples 10 and 11 denote the impact on factors following an increase in the cost of production. Consequently, Example 12 denotes the opposite linkages and captures the induced effects on production prices following exogenous cost increases in factor prices. Example 13 denotes the relationship between factors and endogenous institutions. It traces the increase in the cost of living of households following an increase in factor costs. Increasing labour costs would in turn stimulates commodity prices which ultimately push up households' cost of living. Without the application of the decomposition, it is very difficult to assess the price effects by rules of thumb between producing sectors, factors and endogenous institutions.

The SAM inherits the assumptions put forward by the input-output framework since the they are the core of the SAM. Therefore, these assumptions are important during the interpretation of the results. A detailed explanation of these assumptions can be found in Miller et al. (2009). In the case of this paper, there are particular assumptions worth mentioning. For instance, as opposed to the Leontief Demand-Driven model, the SAM-price model assumes that only prices can fluctuate in the economy, while keeping quantities fixed. Also, there is only one commodity for production in the economy. Therefore, the importance of particular commodities is not captured. This implies that there are no possibilities of substitution between inputs during production. In other words, it is also assumed that purchasers of intermediary inputs do not shift to substitute goods. In fact, commodities would be considered as perfect complements. This strong assumption might not hold in reality because sellers do switch intermediary inputs for their production process as a result of price hikes to minimise costs and safeguard profits.

Also, since the supply of resources is also assumed to be infinite, price multipliers can be utilised to determine any price level following shocks in primary inputs. However, these price levels can be estimated by imposing an important assumption that an economy has unlimited labour supply in its disposal. However, this assumption can be unrealistic because there is a limit to how much resources may be available, especially for a small island developing economy.

By assessing the price multipliers estimated in this study, it is possible to obtain a detailed insight into the price fluctuations in terms of production activities, higher wage costs and cost-of-living adjustments. Furthermore, the price decomposition estimates provide more insight on the price transmission or inter-sectoral relationship patterns in the economy in terms of prices. These estimates can also be utilised by policy makers to identify the impact on prices throughout the economy during policy design, with the aim to gain a deeper insight on the price transmission.

4 Conclusion

The objective of this paper was to estimate the price multipliers and their corresponding decomposition effects within the local context. A 2010 SAM for Malta was utilised as the basis in order to obtain a complete set of price multipliers. As a result of the endogenising feature embedded within the SAM, the price multiplier effects in the presence of endogenous and factor accounts could be appropriately assessed in detail, namely the transfer, open-loop and closed-loop price multiplier effects. In this case, the price effects on households represent simulations of cost-of-living adjustments, while the simulations on the factor account captures the increase in factor prices due to higher wage costs.

These price multiplier estimates are subject to the traditional input-output framework assumptions. However, they also have advantages over the traditional Walrasian price models (Roland-Holst et al., 1995). For instance, a notable advantage is the ability to estimate price changes that are useful for policy making at sectoral level. In terms of prices, the decomposition of multiplier effects can also be utilised to assess the transmission or patterns of inter-sectoral relationships. The transfer, open and closed-loop multiplier effects can be assessed via the block-decomposition method, which enables us to distinguish between price effects explained by inter-sectoral linkages, consumption by households (cost-of-living) and factor prices (wage increases). In other words, the block-decomposition of price multipliers provides the possibility to assess the relationships between production, factors and institutions in terms of cost-linkages.

The estimated price multipliers can be of great importance for policy makers to assess relative price changes between production activities, factors and institutions following recent events of supply shortages, rising import costs and higher wage costs. These events may potentially lead to higher inflation rates locally (CBM, 2021). Since these factors are components of primary input costs, price changes can be assessed via the estimated price multipliers following an exogenous shock in one of these components. Therefore, the price multipliers can be utilised to assess the effects of a one euro exogenous cost change in primary inputs on relative prices. The block decomposition of price multipliers provides detailed insight on tracing the different price effects in terms of input costs, cost-of-living adjustments and wage costs.

A more in-depth analysis can be undertaken on sectoral price linkages to obtain a more comprehensive description of linkages effects on prices. This can be done via the path-decomposition method. Therefore, a further research avenue is to identify and analyse the paths through which cost effects circulate between production activities, factors and institutions throughout the economy.

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Appendices

Sector Number	Sector Name	NACE Rev.2
1	Crop and animal production, hunting and related service activities	A01
2	Forestry and logging	A02
3	Fishing and aquaculture	A03
4	Manufacture of food products, beverages and tobacco products	C10T12
5	Manufacture of textiles, wearing apparel and leather products	C13T15
6	Manufacture of wood and of products of wood and cork	C16
7	Manufacture of paper and paper products, printing and reproduction of recorded media, manufacture of coke and refined petroleum products, chemical products, basic pharmaceutical products and pharmaceutical preparations and rubber and plastic products	C17 to C22
8	Manufacture of other non-metallic mineral products	C23
9	Manufacture of basic metals	C24
10	Manufacture of fabricated metal products, except machinery and equipment	C25
11	Manufacture of computer, electronic and optical products, electrical equipment, motor vehicles, trailers and semi-trailers	C26 to C32
12	Repair and installation of machinery and equipment	C33
13	Electricity, gas, steam and air conditioning supply, water collection, treatment and supply, sewerage; waste collection, treatment and disposal activities; materials recovery; remediation activities and other waste management services	D35 to E39
14	Mining and quarrying and construction	B and F
15	Wholesale and retail trade and repair of motor vehicles and motorcycles	G45
16	Wholesale trade, except of motor vehicles and motorcycles	G46
17	Retail trade	G47
18	Land transport and transport via pipelines, water transport, air transport, warehousing and support activities for transportation and postal and courier activities	H49 to H53
19	Accommodation and food service activities	I
20	Publishing activities, motion picture and music publishing activities; Telecommunications, computer programming and information service activities	J58 to J63
21	Financial service activities, except insurance and pension funding	K64
22	Insurance, reinsurance and pension funding, except compulsory social security	K65
23	Activities auxiliary to financial services and insurance activities	K66
24	Real estate activities excluding imputed rents	L68B
25	Imputed rents of owner-occupied dwellings	L68A
26	Legal and accounting activities; activities of head offices; management consultancy activities	M69 and 70
27	Architectural and engineering activities; technical testing and analysis	M71 and M72
28	Advertising and market research	M73
29	Other professional, scientific and technical activities; veterinary activities	M74 and M75
30	Rental and leasing activities	N77
31	Employment activities	N78
32	Travel agency, tour operator reservation service and related activities	N79
33	Security and Investigation Activities	N80 to N82
34	Public administration and defence; compulsory social security	O84
35	Education	P85
36	Human health activities	Q86
37	Social work activities	Q87 to Q88
38	Creative, arts and entertainment activities; Gambling and betting activities	R90T92
39	Sports activities and amusement and recreation activities	R93
40	Activities of membership organisations	S94
41	Repair of computers and personal and household goods	S95
42	Other personal service activities	S96
43	Activities of households as employers; undifferentiated goods and services producing activities of households for own use	T
44	Activities of extra-territorial organisations and bodies	U

Table 3: Description of the 44 Maltese Economic Sectors Present in the 2010 Micro SAM

Source: (Theuma, 2020).

MacroSAM in Euro Millions (000's)	P	H	F	G	C	E	L	K	T	Tot
Production Activities (P)	3,880.95	3,020.91	0	1,247.73	872.117	8,577.18	0	0	0	17,598.89
Households (H)	0	0	189.79	863.99	0	1,738.25	2,846.27	677.9	0	6,316.21
Enterprises (F)	0	991.14	0	220.08	0	3,982.49	0	2,030.78	0	7,224.54
Government (G)	0	577.48	59.05	0	0	1,123.48	0	251.83	792.74	2,804.55
Capital (C)	0	193.88	-136.78	427.19	0	1,073.94	0	0	0	1,558.18
RoW Imports (E)	7,748.25	1,054.81	7,112.47	32.80	577.46	692.68	0	0	0	17,218.46
Compensation of Employees (L)	2,846.27	0	0	0	0	0	0	0	0	2,846.27
Other Value Added (K)	2,960.51	0	0	0	0	0	0	0	0	2,960.51
Net Taxes on Products and Production (T)	162.908	478	0	12.79	108.64	30.4	0	0	0	792.70
Total (Tot)	17,598.91	6,316.21	7,224.54	2,804.55	1,558.18	17,218.46	2,846.27	2,960.51	792.70	59,320.36

Table 4: Maltese Macro SAM for the reference year of 2010

Source: (Theuma, 2020).

Micro SAM Accounts	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	Factors	Endog. Instit.
1	1.03	0.00	0.02	0.21	0.00	0.00	0.01	0.01	0.00	0.01	0.01	0.04	0.10	0.04	0.01	0.06	0.04	0.05	0.06	0.03	0.06	0.01	0.00	0.01	0.03	0.01	0.01	0.01	0.02	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	1.04	1.09
2	0.01	1.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.06	0.02	0.00	0.16	0.06	0.04	0.04	0.02	0.16	0.01	0.00	0.01	0.02	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.52	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.65	0.68
3	0.01	0.00	1.00	0.02	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.05	0.02	0.00	0.04	0.02	0.11	0.03	0.02	0.06	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.46	0.48
4	0.11	0.00	0.01	1.06	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.01	0.10	0.02	0.00	0.10	0.04	0.06	0.03	0.02	0.06	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.62
5	0.01	0.00	0.00	0.01	1.00	0.00	0.02	0.00	0.00	0.00	0.00	0.01	0.22	0.01	0.00	0.03	0.02	0.07	0.04	0.02	0.05	0.00	0.00	0.01	0.02	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.66	0.69
6	0.01	0.00	0.00	0.01	0.00	1.08	0.01	0.00	0.00	0.00	0.01	0.00	0.05	0.01	0.00	0.08	0.04	0.05	0.03	0.02	0.06	0.01	0.00	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.63
7	0.01	0.00	0.00	0.01	0.00	0.00	1.01	0.00	0.00	0.00	0.01	0.01	0.08	0.01	0.00	0.03	0.02	0.05	0.03	0.02	0.05	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.59	0.62
8	0.01	0.00	0.00	0.01	0.00	0.00	0.01	1.10	0.00	0.02	0.01	0.01	0.08	0.33	0.01	0.09	0.04	0.05	0.04	0.02	0.07	0.01	0.00	0.01	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.62	0.65
9	0.01	0.00	0.00	0.02	0.00	0.00	0.01	0.00	1.00	0.00	0.01	0.00	0.12	0.02	0.01	0.03	0.03	0.03	0.05	0.02	0.05	0.01	0.00	0.01	0.02	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.05	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	1.02	1.06
10	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	1.00	0.01	0.00	0.05	0.02	0.00	0.13	0.05	0.05	0.03	0.02	0.05	0.01	0.00	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.59	0.61
11	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01	1.02	0.00	0.05	0.01	0.00	0.03	0.02	0.03	0.02	0.02	0.04	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.38	0.40
12	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.02	0.03	1.01	0.08	0.03	0.00	0.07	0.02	0.11	0.03	0.03	0.08	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.54	0.56
13	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	1.79	0.03	0.00	0.02	0.02	0.03	0.02	0.03	0.05	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.45	0.47
14	0.01	0.00	0.00	0.02	0.00	0.00	0.03	0.09	0.00	0.05	0.02	0.01	0.06	1.23	0.01	0.08	0.04	0.05	0.04	0.03	0.09	0.01	0.01	0.02	0.02	0.01	0.02	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.69	0.72
15	0.01	0.00	0.00	0.02	0.00	0.00	0.02	0.00	0.00	0.01	0.01	0.01	0.09	0.03	1.01	0.05	0.03	0.12	0.05	0.04	0.11	0.01	0.01	0.04	0.02	0.02	0.01	0.03	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.83	0.87
16	0.01	0.00	0.00	0.02	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.01	0.07	0.03	0.01	1.04	0.03	0.19	0.06	0.04	0.09	0.01	0.01	0.03	0.02	0.01	0.01	0.03	0.00	0.00	0.02	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.91	0.95
17	0.01	0.00	0.00	0.02	0.00	0.00	0.02	0.00	0.00	0.00	0.01	0.01	0.13	0.04	0.01	0.03	1.03	0.09	0.05	0.04	0.12	0.01	0.01	0.05	0.02	0.01	0.01	0.05	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.90	0.94
18	0.01	0.00	0.00	0.02	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.01	0.07	0.04	0.01	0.03	0.03	1.30	0.05	0.04	0.10	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.69	0.72
19	0.03	0.00	0.03	0.13	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.01	0.15	0.04	0.01	0.09	0.04	0.05	1.05	0.03	0.10	0.01	0.01	0.04	0.02	0.02	0.01	0.03	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.74	0.78
20	0.01	0.00	0.00	0.01	0.00	0.00	0.02	0.00	0.00	0.00	0.01	0.00	0.05	0.01	0.00	0.03	0.02	0.04	0.04	1.13	0.11	0.01	0.01	0.01	0.02	0.02	0.00	0.04	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.69	0.72
21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.00	1.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.10
22	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.01	0.00	0.01	0.02	0.03	0.03	0.02	0.07	1.01	0.03	0.00	0.02	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.65	0.68
23	0.00	0.00	0.00	0.01	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.03	0.01	0.00	0.01	0.01	0.04	0.03	0.04	0.11	0.00	1.01	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.43	0.45
24	0.01	0.00	0.00	0.02	0.00	0.00	0.01	0.01	0.00	0.01	0.01	0.00	0.08	0.04	0.01	0.03	0.03	0.04	0.05	0.04	0.12	0.01	0.01	1.06	0.02	0.02	0.07	0.02	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.92	0.96
25	0.01	0.00	0.00	0.02	0.00	0.00	0.01	0.02	0.00	0.01	0.01	0.00	0.04	0.09	0.01	0.03	0.03	0.03	0.06	0.02	0.06	0.01	0.00	0.02	1.03	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	1.05	1.10
26	0.01	0.00	0.00	0.02	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.06	0.02	0.01	0.02	0.03	0.04	0.06	0.05	0.10	0.01	0.04	0.03	0.02	1.02	0.00	0.01	0.01	0.00	0.04	0.01	0.01	0.01	0.02	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.95	0.99
27	0.01	0.00	0.00	0.02	0.00	0.00	0.01	0.04	0.00	0.01	0.01	0.00	0.08	0.11	0.01	0.04	0.03	0.05	0.05	0.06	0.13	0.01	0.01	0.01	0.02	0.02	1.21	0.01	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.85	0.89
28	0.01	0.00	0.00	0.02	0.00	0.00	0.09	0.00	0.00	0.00	0.01	0.00	0.05	0.01	0.00	0.04	0.02	0.05	0.04	0.13	0.27	0.01	0.01	0.01	0.02	0.05	0.00	1.54	0.01	0.01	0.00	0.01	0.02	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.70	0.73
29	0.01	0.00	0.00	0.01	0.00	0.00	0.03	0.00	0.00	0.00	0.01	0.00	0.07	0.02	0.00	0.04	0.02	0.04	0.04	0.03	0.14	0.01	0.01	0.01	0.02	0.02	0.01	0.03	1.13	0.00	0.00	0.00	0.02	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.67	0.70
30	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.01	0.04	0.02	0.03	0.03	0.02	0.07	0.04	0.03	0.25	0.01	0.01	0.01	0.02	0.01	0.00	0.01	0.00	1.02	0.03	0.00	0.02	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.62	0.65
31	0.01	0.00	0.00	0.02	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.10	0.02	0.01	0.03	0.03	0.04	0.06	0.04	0.06	0.01	0.00	0.01	0.03	0.01	0.00	0.01	0.00	0.00	1.02	0.01	0.01	0.00	0.04	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	1.04	1.09
32	0.01	0.00	0.00	0.02	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.01	0.07	0.02	0.00	0.02	0.02	0.13	0.11	0.05	0.10	0.01	0.01	0.02	0.02	0.01	0.00	0.04	0.01	0.00	0.00	1.28	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.67	0.70
33	0.03	0.00	0.00	0.02	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.07	0.05	0.01	0.05	0.03	0.04	0.05	0.03	0.07	0.01	0.01	0.02	0.02	0.01	0.00	0.01	0.00	0.00	0.00	0.01	1.08	0.00	0.02	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.97	1.01
34	0.01	0.00	0.00	0.02	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.10	0.05	0.01	0.03	0.03	0.04	0.06	0.07	0.06	0.01	0.00	0.01	0.02	0.01	0.01	0.01	0.00	0.00	0.02	0.01	0.03	1.01	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.92	0.97
35	0.01	0.00	0.00	0.02	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.07	0.04	0.01	0.02	0.03	0.03	0.06	0.03	0.05	0.01	0.00	0.01	0.03	0.01	0.00	0.02	0.00	0.00	0.00	0.01	0.01	0.00	1.02	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	1.06	1.11
36	0.01	0.00	0.00	0.02	0.00	0.00	0.02	0.00	0.00	0.00	0.02	0.00	0.10	0.03	0.01	0.05	0.04	0.03	0.06	0.03	0.04	0.01	0.00	0.01	0.02	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.02	0.00	0.01	1.01	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.95	1.00
37	0.01	0.00	0.00	0.02	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.14	0.03	0.01	0.02	0.03	0.03	0.05	0.04	0.06	0.01	0.00	0.01	0.02	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.01	0.00	0.02	0.03	1.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.97	1.01
38	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.01	0.01	0.01	0.02	0.04	0.05	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.01	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.42
39	0.01	0.00	0.00	0.02	0.00	0.00	0.05	0.01	0.00	0.00	0.01	0.00	0.18	0.07	0.01	0.06	0.03	0.11	0.05	0.05	0.13	0.01	0.01	0.02	0.02	0.02	0.01	0.04	0.00	0.00	0.00	0.01	0.05	0.00	0.03	0.01	0.00	0.01	1.02	0.00	0.00	0.00	0.00	0.00	0.75	0.79
40	0.01	0.00	0.00	0.02	0.00	0.00	0.01	0.01	0.00	0.01	0.01	0.00	0.08	0.08	0.01	0.05	0.03	0.03	0.05	0.03	0.09	0.01	0.00	0.02	0.02	0.01	0.01	0.01	0.01	0.00	0.00	0.02	0.12	0.00	0.02	0.01	0.00	0.01	0.00	1.00	0.00	0.01	0.00	0.00	0.93	0.98
41	0.01	0.00	0.00	0.02	0.00	0.00	0.01	0.00	0.00	0.01	0.06	0.00	0.06	0.02	0.00	0.06	0.03	0.04	0.04	0.03	0.07	0.01	0.01	0.02	0.02	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.01	0.00	0.02	0.00	0.00	0.01	0.00	0.00	1.00	0.00	0.00	0.00	0.75	0.79
42	0.01	0.00	0.00	0.02	0.00	0.00	0.08	0.01	0.00	0.00	0.01	0.00	0.11	0.04	0.01	0.11	0.05	0.04	0.04	0.03	0.07	0.01	0.00	0.01	0.02	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	1.02	0.00	0.00	0.79	0.83
43	0.01	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.01	0.01	0.02	0.03	0.02	0.06	0.02	0.04	0.01	0.00	0.01	0.03	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.01	1.00	0.00	1.16	1.22
44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00
Factors	0.01	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.01	0.01	0.02	0.03	0.02	0.06	0.02	0.03	0.01	0.00	0.01	0.03	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	1.18	1.23
Endog. Instit.	0.01	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.01	0.01	0.02	0.03	0.02	0.06	0.02	0.03	0.01	0.00	0.01	0.03	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.19	1.29

Table 5: Leontief Transposed SAM Multiplier Matrix (M')

Source: (Theuma, 2020).

Abela, D. (2022). *Xjenza Online*, 10(1): 48–60.

Xjenza Online: Science Journal of the Malta Chamber of Scientists
www.xjenza.org
DOI: 10.7423/XJENZA.2022.1.06

Review Article

Elastomers for the Development of Orthopaedic Implants - A Review

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Abstract. There has been an increase in the use of elastomers in the biomedical industry. Recent developments in utilising elastomers for use in orthopaedic implants has shown the great potential of these materials for long-term implantation. Elastomers are being developed for applications in tissue engineering, polymeric scaffolds and synthetic implants, all with the aim of repairing or maintaining orthopaedic joints in working order. The aim of this review is to discuss current developments in elastomeric orthopaedic implants and their most utilised materials namely silicones, polyurethanes and hydrogels. Polyurethane and silicone elastomers are commonly used in bulk implantable devices due to their good mechanical properties, chemical resistance and biocompatibility. Other materials such as polycarbonate urethanes (PCUs) are being utilised as means to protect the joints due to their superb mechanical properties and wear characteristics. The range of applications of elastomers vary from hip joint replacements, such as in the case of the TriboFit® implant, meniscal implants, and first metatarsophalangeal joint replacements. More recently hydrogels have been utilised as coatings for increased lubrication in joint replacements, as a substitute for articular cartilage. Applications of hydrogels vary from improving the collagen and proteoglycan content of the joint to improving the load distribution across the joint in arthritic knee joints. The use of elastomers in orthopaedic implants is still in its infancy; and whilst a large amount of the research being done is still in the prototype stages, the potential of these materials and devices is virtually unlimited.

Keywords: elastomer, bioelastomer, biomaterial, biomedical, implants, orthopaedic

1 Introduction

The application of elastomeric polymers for biomedical implants has recently been on the rise. Elastomers are a sub-class of the polymer family, which have a low amount of inter-molecular forces, which together with their flexible and soft nature allow them to have a particularly high elongation (Özdemir, 2020). As such, elastomers are materials which are capable of showing large and rapid strain in response to an applied stress (Shanks et al., 2013). In general elastomers have large toughness values, having the ability to absorb energy under stress. Additionally, the term 'bioelastomer' refers to those elastomers which exhibit good biocompatibility in the implantation site, a glass transition temperature below the body temperature (35 - 40°C), while also having the ability to return to at least 1.25-fold of their original length after 1 minute of release if stretched to 1.5-fold of their original length for 1 minute, maintaining stretch stresses in the range of 0.1 - 20 MPa (Shi et al., 2009).

While a large portion of the use of elastomers in the biomedical field still remains in the sector of non-physiological contact biomedical devices, such as syringes and disposable gowns for surgeons and operating tables, there has been an increasing interest in the use of these materials for implants with physiological contact including orthopaedic applications, dental reconstruction, contact lenses, cardiovascular devices, catheters, sutures, adhesives, and membranes amongst others (McMillin, 2006).

There has also been an interest in replacing traditionally metallic implants with polymeric ones, creating lighter devices due to the inherently lower density of polymers. Simultaneously, complex shapes can be created with the possibility of large-scale production, thus greatly reducing

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manufacturing and processing costs while creating flexibility in the design of the material for specific applications (Festas et al., 2020).

There are three main types of elastomers which are used in biomedical devices, namely: (i) commodity elastomers, (ii) medical-grade biodegradable elastomers for short-term physiological contact and (iii) medical-grade non-biodegradable elastomers for long-term physiological contact (Basak, 2021).

All implantable bioelastomers need to satisfy the twin requirement of surface compatibility and adequate long-term mechanical properties which are dependent on the application *in vivo*. Bioelastomers have to be tested on the medical device for which they are intended, since their manufacturing process may affect the long-term capability of the material, by using standard practices issued by recognised institutions, such as Directive 90/385/EEC, consisting of EU regulations regarding implantable medical devices.

Table 1 shows a list of the elastomer properties which are required for orthopaedic implantation. Validation methods for the mechanical properties required are dependent on the application. For instance the validation of cardiovascular and pressure devices are different as shown by Kanyanta et al. (2010) for a polyurethane elastomer used in a cardiovascular application and by Courtney et al. (2001) for a shock absorbing elastomer composite, where the former material was tested under uni-axial, planar and equibiaxial tension, stress relaxation, creep and cyclic loading, while the latter was tested for impact absorption characteristics.

To predict the durability and fatigue lifetime of an elastomer, the biaxial stress-deformation at high strain rates of the elastomer has to be known. The elastomer will fail due to fatigue when it experiences a stress which is far below the static mechanical strength (Yoda, 1998).

Elastomers which have to be inserted in a physiological environment have to utilise the least amount of toxic catalysts and leaching polymer additives to reduce the occurrence of unwanted or damaging reactions, which is also affected by the manufacturing process. Silicones and polyurethanes are those elastomers from which the smallest amount of toxic chemicals are extracted (Yoda, 1998). Finally, the bioelastomer has to be sterilised before making physiological contact to remove any components which might be detrimental to the function. Each elastomer has its own specific and applicable sterilisation technique. Some of these techniques are mentioned in Table 1.

This paper sets out to compile a review of elastomeric materials currently being utilised for the development of orthopaedic implants, including silicones, polyurethanes and hydrogels. Following this, a review of the current developments being made in the field of orthopaedic implants will be presented, starting with a case study on a total hip replacement followed by the evolution of first metatarsophalangeal joint replacements and ending with elastomers used as meniscal implants in the knee joint.

2 Elastomeric Polymers for Biomedical Use

2.1 Silicones

Silicone (also known as polysiloxane) is the most common elastomer currently used in the biomedical industry. It is composed of silicon, carbon, oxygen and hydrogen (Shit et al., 2013). The physical properties of this material are determined by the chain length and the degree of cross-linking. Silicone has good biocompatibilty and excellent bio-durability with host tissue in orthopaedic implantation sites. These characteristics give silicon the ability to be in a physiological environment while maintaining minimal tissue interaction and keeping deterioration of the properties to a minimum over a long period of time. Moreover, the response of the tissue on the silicon is very low since the material is resistant to attack by the surrounding tissue and cannot be metabolised by other organisms. This high resistance to external attack originates from the ionic Si-O bonds in the structure, giving high bond strength (Zare et al., 2021).

Silicones have been used in a range of applications, varying from catheters (Folysil® and Prosys® Foley catheter) and other short-term implants to inserts and other implants used to replace or repair parts of the body for long-term use, such as mammary implants (Allergan Natrelle®, Mentor® Memory Gel®). As early as the 1960's, implants were being developed in the field of or-

Property	Description
Physical Properties	High elasticity, moderate strength, durability, stability
Manufacturability	Injection moulding, extrusion, solvent casting, calendering
Biocompatibility	Non-allergenic, non-carcinogenic, non-mutagenic, non-toxic, hemocompatible
Sterilisability	Steam autoclaving, dry heating, ethylene oxide gas, electron and gamma irradiation

Table 1: List of properties required by elastomers for orthopaedic implantation (Özdemir, 2020; Shi et al., 2009; Yoda, 1998).

thopaedics, where silicone was used as a spacer to replace tissue and cartilage function in the finger joints. It was also adopted in the total knee replacement procedure, where it acted as a shock absorber between the femoral and tibial components (Moximed® Calypso® Knee System) (Zare et al., 2021). Medical-grade silicone is available in different varieties depending on the application. Typical silicone is compounded using very fine and pure amorphous silica which is used as a filler to improve the tear and tensile strength. Any fillers which remain present will affect the blood compatibility of the silicones. Studies are currently under way to investigate the possibility of processing silicones without fillers utilising polydimethylsiloxane as the main backbone of the polymer chain, terminating in acetoxy groups, such as in the elastomer Cardiothane 51 (Yoda, 1998).

Silicones with biocompatible fillers are prepared using modified silica in two ways: a) silica bonded with antithrombogenic heparinoid agent (to prevent blood coagulation); and b) silica bonded to reactive H-Si groups obtained by the reaction of the silica with methyldichlorosilane. Such silicones exhibit good mechanical properties as well as excellent tissue compatibility.

Silicones tend to exhibit good blend compatibility with various block copolymers such as SBS (styrene-butadiene-styrene) and SEBS (styrene-ethylene/butadiene-styrene). These blends yield good surface and processing properties. Polypropylene also exhibits good blend compatibility when added to silicone modified block co-polymers, giving a uniquely favourable balance of properties intended for biomedical use. These silicone elastomer/PP blends contain no phtalate plasticisers and still exhibit silicone-like surface properties coupled with thermoplastic processability and improved elastomer strength properties.

Thermoplastic silicones include a range of silicone copolymers and block co-polymers, such as silicone-urethane and silicone-polycarbonate. Some of these silicones have been developed with exceptional blood contacting properties and reasonably good physical properties. The properties of these materials vary greatly from typical silicones in that they exhibit higher mechanical strength amongst other varying properties (Arkles et al., 1983). A common silicone-urethane used in biomedical devices is Cardiothane 51, which is a co-polymer of polydimethyl-siloxane and aromatic polyether urethane, cross-linked by the interaction of acetoxy-terminated siloxane blocks with substituted urethane nitrogens. The properties related to this material include good biocompatibility (especially in cardiovascular applications), excellent fatigue strength, toughness and flexibility (Nyilas et al., 1977).

2.2 Polyurethane Elastomers

Polyurethane elastomers (PUs) are considered amongst the best performing medical-grade polymers available in the biomedical industry. Their biological and mechanical properties make them suitable to be utilised in a range of implantable medical devices, since they exhibit an exclusive combination of biocompatibility, biostability, flexibility, toughness and durability (Christenson et al., 2007; Khan et al., 2005b). Table 2 shows a list of properties and characteristics for silicone compared to polyurethane.

PUs typically have a more complex structure than most common polymers like polystyrene or polyethylene which are composed of one or two monomer units. Instead, they comprise of: (a) a flexible polyol (or macrodiol), also referred to as the soft segment, having a stiff part based on a diisocyanate and (b) a chain extender, referred to as the hard segment (Kébir et al., 2017). The ability to utilise different variations of the three components during processing leads to PUs with varying mechanical and physiochemical properties (Christenson et al., 2007; Khan et al., 2005a). The structure of PUs is normally a two-phase structure comprising of aggregated semi-crystalline micro-domains dispersed in an amorphous structure. As such they are referred to as segmented block co-polymers. The predominant linkage which is present in the soft segment will identify the type of PU, for instance poly-(etherurethanes) contain ether moieties, poly-(esterurethanes) contain ester linkages, while polycarbonate urethanes (PCUs) contain carbonate linkages (Elsner et al., 2017).

The first biomedical PUs, poly-(ester urethanes), were found to be unsuitable for implantation due to rapid hydrolitic deterioration of the aliphatic polyester soft segment in the PU. Subsequently, poly-(ether urethanes) were utilised as a substitute due to their improved hydrolitic stability. However, implants made from softer grades of the material still failed due to oxidative deterioration originating from metal-ion oxidation and environment stress cracking (Wiggins et al., 2001; Zhao et al., 1990). Failure of PU-based implants such as breast implants and pacemaker leads in the 1980s led to the scrutiny on the suitability of the material for long-term implantation (Elsner et al., 2017). PCUs were subsequently developed to compensate for the problems related to stress-cracking and degradation created by the ester and ether linkages in the PU. They showed a promising long-term biostability, with excellent resistance to metal ion oxidation, environmental stress cracking and hydrolysis. More recently, silicone has been introduced in the PCU backbone creating silicone copolymers (PCU-S), which have been found to exhibit improved biostability (Elsner et al., 2017).

Property	Silicone	Polyurethane
Elastomeric Properties	Good and Uniform	Excellent
Biocompatibility	Moderate	Excellent
Temperature Resistance	Excellent	Excellent
Biodegradation Resistance	Excellent	Moderate
Oxidation Resistance	Excellent	Moderate

Table 2: List of material properties and characteristics for silicone and polyurethanes for orthopaedic implantation (Christenson et al., 2007; Khan et al., 2005b).

Siebert et al. (2008) show how the Young's Modulus of PCU is very similar to that of cartilage when compared to ultra-high molecular weight polyethylene (UHMWPE). This is beneficial in orthopaedic applications such as the hip and knee joints, where a close match of the Young's Modulus of the materials in contact is essential for the long-term behaviour of the implant. When there is contact between materials with a large mismatch in the Young's Modulus (as in the case of UHMWPE and cartilage), stress transfer to the bone is prevented which could eventually result in bone resorption and implant loosening, in a phenomenon called stress shielding (Aherwar et al., 2016). The stress-strain behaviour of a hyperelastic material such as PCU also comes into play when investigating the material for potential applications in orthopaedics. Mechanical compression tests conducted by Linder-Ganz et al. (2010) revealed that the peak stresses investigated in a PCU meniscal implant were lower than the maximum allowable stress for the material. Similarly, the peak tensile stress was lower than the material's yield strength. Shemesh et al. (2014) conducted other biomechanical tests on the same implant to investigate the strain rate, creep, hysterisis and relaxation measurements in diluted bovine serum, against polyethylene (PE) copies of the femur and tibia. Interestingly, since the implant was effectively a composite of PCU and UHMWPE fibres, the results varied from tests conducted on pure PCU described by Elsner et al. (2015). The stress-strain behaviour for the pure PCU could be described in three phases: (i) Phase I - a linear phase at which the implant exhibited a relatively low Young's Modulus, E, (18 MPa); followed by (ii) Phase II - a non-linear stiffening phase at 20-50 % strain; and finally (iii) Phase III - a linear phase with a lower resistance to strain (10 MPa). However, an increase in the Young's modulus was noted for the composite from Phase I to Phase III (from 3 to 4 MPa). This different behaviour could be attributed to the effects of the reinforcing fibres, which improved the resistance to strain, rather than reducing it.

A series of polyurethanes and polyurethane-ureas of varying degrees of hydrophilicity (they are able to retain water in their structure without dissolving) and hydrophobicity were investigated as candidates for prosthetic replacement of articular cartilage, artificial joint prostheses and percutaneous (beneath the skin) implantable devices (Yoda, 1998). Porous aliphatic polyurethanes were implanted as trials for meniscal reconstruction due to their biodegradable response and were prepared using two different techniques: a) in situ polymerisation; and b) freeze-drying/salt leaching. Results revealed that implants with a macro-porous structure cross-linked with a micro-porous structure showed excellent ingrowth of fibrocartilaginous tissue (de Groot et al., 1990; Elema et al., 1990).

Polyurethane tribological behaviour in a hip joint replacement is dependent on a thin lubricating layer between the articulating surfaces which has to separate the two surfaces under continuous cyclic conditions. Biologically, this is similar to the behaviour exhibited by natural joints as a result of the relative motion created due to the pressure in the synovial fluid and the elastic deformation of the cartilaginous surfaces (Groen et al., 1991). The leading lubrication regime in the tribological behaviour of soft PCU bearing surfaces is composed of a mixture of elastohydrodynamic (EHL) and microelastohydrodynamic (μ-EHL) lubrication systems (Auger et al., 1993; Dowson et al., 1991). The first system occurs when the pressure generated in the lubricating film is sufficient to initiate deformation on any surface so that the articulating surfaces are kept apart. The second system is a localised form of EHL, where the pressure maintains a continuous lubricating film by flattening asperities in the material's surface. Tribological testing conducted by Scholes et al. (2006) on Corethane 80A (medical grade thermoplastic PU), articulating against standard, commercially available femoral heads (CoCrMo and Al_2O_3) exhibited low friction values which were similar to a full fluid-film lubricating regime, with a reported 1% asperity contact. Smith et al. (2000) also reported positive results for friction tests of PU cups (made from a combination of Corethane blends) with respect to typical UHMWPE cups rubbing against CoCrMo femoral heads in 25% calf serum (12.0 ±3.6 mm^3/Mc vs. 48.2 ±3.7 mm^3/Mc (volume lost per million cycles)). On the other hand, the behaviour of PU in knee joint replacements is dependent on a mixed lubrication regime, however, while it still benefits from a substantial measure of fluid film lubrication, μ-EHL preserves low friction by providing thin, but effective fluid films (Auger et al., 1995; Scholes et al., 2006). Luo et al. (2010) investigated PU as a potential candidate for hemiarthroplasty (replacement of half a joint), instead of the current stainless steel state-of-the-art. Tests on a pendulum friction simulator of PU tibial plates with different elastic moduli (1.4 - 22 MPa) sliding in bovine serum against healthy bovine femoral condyles revealed that PU with lower moduli reduced friction shear and contact stresses, with an observed reduction in the cartilaginous . The higher modulus PU exhibited higher levels of friction shear stresses, however the wear on the cartilage observed was still lower than when stainless steel tibial plates were utilised. This is supported by another study by Pöllänen et al. (2011) who also concluded that PU is more compatible in contact with cartilage than stainless steel.

2.3 Hydrogels

Hydrogels have been on the rise in the last decade as biomaterials due to their excellent biocompatibility and their ability to be manufactured with different properties depending on the application, being biphasic by nature. Although not all hydrogels are elastomeric in nature, hydrogels can be termed as 'elastic polymers' when they exhibit viscoelastic properties. This behaviour is dependent on the groups and linkages making up the structure. As a bulk polymer, hydrogels are normally lacking in the mechanical strength and elasticity required for rigid applications, although some have shown that hydrogels can be be utilised as load-bearing meniscal implants in small animals (Kelly et al., 2007a; Kobayashi et al., 2003). However the main use for hydrogels still remains in coating applications. Medical implants coated with hydrogels have the double advantage of having desirable bulk and surface properties (Yoda, 1998).

Hydrogels are artificial materials consisting of a 3-D structural network which spans across a medium and holds through surface tension. The internal network structure is held together by means of chemical or physical bonding, creating chemical and physical hydrogels respectively. One of the main properties of hydrogels is that they are hydrophilic. The cross-linking of the structure may be either covalent or ionic, with assistance from weaker bonds such as van der Waal forces and hydrogen bonding. Non-cross-linked hydrogels also exist, which are held together by means of crystallites present in the structure, which are insoluble and hence act as physical cross-links. A useful designation for hydrogels being used in the biomedical industry is to divide them as being neutral/nonionic, anionic, cationic or zwitterionic (Kyomoto et al., 2015). Table 3 refers to some typical hydrogels used in the biomedical industry together with their designation.

Polyvinyl alcohol (PVA) was shown to be functionally and structurally similar to cartilage by Bray et al. (1973). The alcoholic functional group in the structure is responsible for the chemical versatility of the hydrogel, while the hydroxyl groups contribute to its hydrophilic nature. PVA-based hydrogels can be manufactured by forming acetal linkages utilising di-functional cross-linking agents. PVA hydrogels were investigated as coatings in orthopaedic applications due to the similar lubrication and mechanical properties to articular cartilage. Ushio et al. (2003) investigated PVA hydrogels in conjunction with a titanium fiber mesh for a bone fixation arthroplasty in hemi-arthroplasty of the acetabulum. Excellent lubricity was noted at the hydrogel/natural articular cartilage interface.

2-Methacrylolyloxyethyl phosphorylcholine (MPC) was developed by Ishihara et al. (1990) and is a biocompatible polymer which mimics the neutral phospholipids of the cell membranes. These polymers are some of the most biocompatible polymers investigated to date and also exhibit low friction and high lubricity. Arakaki et al. (2010) investigated the effect of a poly (2-acrylamido-2-methylpropane sulfonic acid)/poly(N, N-dimethyl acrylamide) (PAMPS/PDMAAm) double-network hydrogel as a counter-face cartilage in rabbit knee joints. The role

Electric charge	Typical monomer	Hydrophilic group
Nonion	Vinyl alcohol (VA)	$-OH$
	2-Hydroxyethyl methacrylate (HEMA)	$-C_2H_4OH$
Cation	2-(Dimethylamino)ethyl methacrylate (DMAEMA)	$-NR_2H^+$
Anion	Acrylic acid (AA)	$-COO^-$
Zwitterion	2-Methacrylolyloxyethyl phosphorylcholine (MPC)	$-PO_4{}^-(CH_2)_2N^+\equiv$

Table 3: List of hydrogels with their electric charge and hydrophilic group used in the biomedical industry. Adapted from Kyomoto et al. (2015).

of the implant is to act as an artificial cartilage in defect locations where cartilage degeneration has occurred, mainly due to osteoarthritis. The study revealed that the hydrogel exhibited an extremely low coefficient of friction with respect to the original cartilage, with no detrimental effects on the counter-bearing cartilage.

3 Orthopaedic Implantable Devices using Elastomeric Biomaterials

3.1 Hip Joint Replacement - The TriboFit® Acetabular Buffer - Case Study

Total hip replacements continue to face complications related to osteolysis, wear, fatigue and squeaking. These problems, which are also present in the current state-of-the-art implants, contribute to early implant loosening and premature failure. In 2006, the first instance of polycarbonate urethane (PCU) as a substitute material for hip joint replacements was presented as a commercial cushion-bearing system in the form of an acetabular component, aptly named TriboFit® acetabular buffer (Active Implants, LLC Memphis, TN). The hip replacement consisted of the PCU acetabular intermediary buffer placed between a CoCr femoral head and shell, as shown in Figure 1 (Kelly et al., 2007b).

The purpose of using PCU in the implant was for the material to behave in a similar manner to the natural hip on the acetabular side, with the intention of reducing bone removal during the implantation, by modifying only the acetabulum. Other advantages of using an elastomer as the acetabular component include improved ease of insertion and locking stability of the implant due to a 'snap fit' locking mechanism (Elsner et al., 2017).

In vitro investigations presented by Jennings et al. (2002) on the wear behaviour of the buffer sliding against bone in diluted calf serum (25%) revealed that the wear rate was 2.8 mm^3/Mc after 5 million cycles in a replica of the acetabulum. John et al. (2012) compared wear behaviour of PCU buffers, UHMWPE and cross-linked UHMWPE sliding against cobalt-chrome alloy femoral components. Over 5 million cycles, PCU was reported to have the lowest average material loss (19.1 mm^3/Mc), followed by cross-linked UHMWPE (25 mm^3/Mc) and UHMWPE (100 mm^3/Mc). The large reduction of material loss exhibited by PCU was attributed to the microelastohydrodynamic lubrication (μ-EHL) of PCU in a hemispherical configuration when rubbing against a hard bearing surface. Elsner et al. (2011) have conducted the longest laboratory study on this commercially-available PCU buffer, implanted against a metal shell. After 20 million cycles, the PCU exhibited excellent wear characteristics, with a low particle generation rate (2-3 $\times 10^6$ particles/Mc) and a steady volumetric wear rate (5.8 - 7.7 mm^3/Mc). The former value is in the order of 6-8 orders of magnitude lower than metal-on-metal bearings and 5-6 orders of magnitude lower than cross-linked UHMWPE. These results were reinforced by profilometry and atomic force microscopy analysis on the PCU buffer after testing, where low damage was observed. One of the most positive conclusions from this study revealed that only 3.4% of the particulates generated by the PCU sliding against the metal were in the range of 0.2 - 10 μm in size, with the large majority of particles being considered as large size (Elsner et al., 2010a). It has been shown that smaller sized particulates often lead to macrophage formation which produce high levels of cytokine tumor necrosis factor (TNF-α), which then leads to osteolysis & aseptic loosening (Keegan et al., 2007; Manley et al., 2008).

Figure 1: TriboFit® Acetabular Buffer (Active Implants, LLC Memphis, TN). Reprinted with permission from Begell House Inc. Publishers from (Kelly et al., 2007b).

Elsner et al. (2017) tested the *in vivo* bio-compatibility and bio-stability of the PCU buffer implant in a sheep model for 6, 12 and 24 months. A variant of the implant having the Co-Cr shell coated with hydroxyapatite was also investigated. In all cases, no functional or gait issues were reported in the sheep and implant. Additionally no gross macroscopic damage in the form of abrasion was observed on the surface of both variants. The hydroxyapatite coated variant exhibited tight fixation of the Co-Cr shell to the acetabulum. The authors attribute the improved fixation to new bone which infiltrated the HA coating. Histological analysis of the retrieved implants revealed that the surrounding tissue did not exhibit any adverse biological response to the implant components, with minimal wear particles being detected.

The TriboFit® Acetabular buffer has been utilised clinically since 2006. In 2013, more than 1200 patients were implanted with the buffer, with the longest implantation time being 7 years (in 2013). By 2017, more than 1800 patients were utilising the implant with the longest implantation time being 10 years. Wippermann et al. (2008) and Siebert et al. (2008) both analysed retrieved TriboFit® implants at 10.5 and 12 months post-implantation. Both patients experienced hip pain around 8 months after implantation. The average wear rates were found to be 1.5 mm^3/year and 15 mm^3/year respectively. The change in volumetric wear by an order of magnitude after only 1.5 months was attributed to the accumulative effect of debris wear, which considerably increased the wear rate.) According to Wippermann et al. (2008) the average particle size was 2.7 μm (range, 0.5 - 90 μm) by scanning electron microscopy and 0.9 μm by laser diffraction analysis. These values were smaller than those reported in the *in vitro* testing. One of the possible explanations which led to this observation could be that only the particles present in the synovial fluid were analysed, and since smaller particles tend to get dispersed more easily in the synovial fluid, there was a tendency towards a lower particulate size range.

Giannini et al. (2011) conducted a randomised study on the PCU buffer, where they compared the clinical outcomes of 60 osteporotic patients treated for femoral neck fracture, either by means of the TriboFit® PCU buffer or by bipolar hemi-arthroplasty (a surgical procedure which replaces the head of the damaged femur with an implant to stabilize the femur and restore hip function), investigated at 3 and 12 months post-insertion. Interestingly, no statistical differences were observed between the two groups. Additionally, no major adverse complications were reported, and the authors described the procedure to be fast and simple. Another recent study by Moroni et al. (2012) investigated the serum Cr and Co levels in two groups of patients fitted with metal-on-metal total hip arthroplasty and the other with the TriboFit® buffer. A higher metal ion content was observed in the patients fitted with the metal-on-metal implants, where the median levels of Co and Cr were found to be 5.4 and 4.8 times higher respectively than those having the TriboFit® buffer. Additionally, no osteolysis or loosening of the PCU buffer was reported. Elsner et al. (2017) report that until 2017, from 184 implanted PCU buffers, no revision surgeries were required in the patients, up until 5 years follow-up. Currently TriboFit® is the only uncemented acetabular cup with a 0% revision rate after 5 years.

3.2 First Metatarsophalangeal Finger Joint Implants

First metatarsophalangeal joint (great toe) implants are inserted to replace the named joint as an alternative treatment to patients with end-stage arthritis, with the intention of relieving pain and restoring motion (Butterworth et al., 2019; Kawalec, 2017). Utilising metal-based metatarsophalangeal implants results in adverse effects on the region including implant loosening, bone resorption and implant instability. With the introduction of silicone, a single-stem silicone elastomeric implant could be inserted to restore the biomechanical function of the joint, following a resection arthroplasty procedure (Esway et al., 2005; Swanson et al., 1991). However, the adverse wear behaviour of the implant which was rubbing against the natural joint surface was concerning (Esway et al., 2005; Kampner, 1984).

Figure 2: First metatarsophalangeal joint implant with metal grommet. Reprinted with permission from Elsevier from (Esway et al., 2005).

An improved iteration of the implant was created using a constrained double-stemmed silicone elastomeric implant, which had a flexible hinge to replace the head of the first metatarsal and the base of the proximal phalanx (Esway et al., 2005). However, this implant still resulted in failure due to wear and tear caused by the high shear force at the joint, in conjunction with continuous contact of the implant with the sharp edges of the bones (Swanson et al., 1991).

The eventual introduction of metal grommets to the double-stemmed implants, shown in Figure 2, reduced the occurrence of failure, by creating an interface between the bone and the silicone. The first metatarsophalangeal joint implants also act as dynamic spacers, restoring motion to the joint while retaining the alignment and the joint space. However, adverse effects due to degradation have been reported including synovitis, osteolysis and lymphadenopathy caused by particulate debris released from the silicone (Péoc'h et al., 2000; Tang et al., 1995).

3.3 Meniscal Implants

The knee joint comprises of three bones and a complex structure of ligaments and tissue. The bones are the femur, tibia and patella, which are joined together to form a double-jointed structure, namely the patello-femoral and tibio-femoral joints. The tissues include the articular cartilage, synovial membrane and menisci (Affatato, 2015).

The tibio-femoral joint is made up of the femoral condyles articulating against the tibial plateau. The femur's (thigh bone) distal epiphysis is segmented into two condyles, whose geometry remains the most important factor when studying knee stability. The lateral condyle is flatter than the medial, while also being larger, to allow transmission of weight to the tibia, since it is more aligned to the femoral shaft. On the other hand, the medial condyle is narrower, however it has a larger rolling surface, giving it a larger effective articulating area. The femur rubs against the proximal end of the tibia across the tibial plateaus. The superior end of each plateau and the inferior end of the femoral condyles are protected by a layer of hyaline cartilage, which is necessary for skeletal elements to slide and rotate against each other with a low degree of friction, while also allowing for load distribution across the joint (Affatato, 2015).

The menisci, having a complex anatomy, are utilised in a variety of biomechanical functions including load bearing, increasing the contact area of the femur whilst guiding rotation and also in partaking in stabilisation during translation motion. The medial meniscus has a semi-circular shape, while the lateral meniscus has a more circular shape, covering a larger area of the tibial plateau (Affatato, 2015; Flandry et al., 2011). Studies focusing on the effect of meniscal tears have revealed that with the loss of meniscal function, there is an increase in degenerative disease, particularly osteoarthritis, possibly due to a change in the load distribution (Englund et al., 2004; Li et al., 2006; Mcdermott et al., 2006). It was also reported that approximately 50% of partial or total meniscectomy patients will suffer from eventual osteoarthritis (Englund et al., 2004). This leads to the notion that the articulating surfaces might be protected by preserving the menisci or by replacing them. Current technology in the field includes tissue engineering in the form of meniscal allografts, which while proven to improve healing and pain relief (Verdonk et al., 2005), still present problems associated with size, rate of disease progression and cost (Cole et al., 2003). There has also been a surge in biodegradable meniscal substitutes made from both synthetic and natural polymers. However these types of materials are generally susceptible to failure under the harsh loading conditions of the knee joint (Kelly et al., 2007a; Kobayashi et al., 2003). Currently the challenge resides in developing synthetic meniscal implants which can withstand the load at the joint, providing a stable biomechanical function, while also being durable and having desirable wear characteristics to function in the knee joint.

Both Kobayashi et al. (2003) and Kelly et al. (2007a) investigated the use of hydrogels as possible meniscal implants to be utilised instead of meniscal allografts. Kobayashi et al. (2003)'s study on rabbits using polyvinyl-alcohol hydrogel (PVA-H) meniscal implants revealed that changes in the articular cartilage was observable after 4-6 months in both meniscectomised (partially removed meniscus by surgery) and implanted knee joints. However, a follow-up after 1 and 2 years revealed that there was little to no subsequent damage after the initial observable degeneration of the implanted joints, while the meniscectomised knees led to more severe damage of the cartilage and even eventual osteophyte formation. Additionally, the implants exhibited good behaviour during implantation, with good wear characteristics and no indication of infection. Kelly et al. (2007a)'s hydrogel-based meniscal implant (Figure 3 (a)) was investigated using an ovine model. The implants, similar to Kobayashi et al. (2003), did not exhibit evidence of permanent deformation or mechanical failure after 2-4 months, in conjunction with no infection observed in the joint of the animal. However, investigation after 1 year of implantation revealed that the hydrogel implant failed in all animals due to a radial tear, which might indicate that the hydrogel composition did not provide the correct mechanical prop-

Figure 3: Implant developed or investigated by: (a) Kelly et al. (2007a) (b) Zur et al. (2011), (c) A. C. T. Vrancken et al. (2017). Reprinted with permission from (a) SAGE publications from (Kelly et al., 2007a); (b) Springer Nature from (Zur et al., 2011) and (c) PLOS ONE from (A. C. T. Vrancken et al., 2017).

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erties for the application. Other sources of failure could have occurred from size mismatch of the implant to the knee joint or due to improper fixation of the implant. In fact, Kobayashi et al. (2003)'s implants were fixed peripherally with sutures with no radial tears, while Kelly et al. (2007a)'s study did not perform this type of fixation.

Studies on Teflon and Dacron meniscal substitutes resulted in failure due to wear-particle induced synovitis (Messner, 1994; Messner et al., 1993).

Li et al. (2006) discuss how the combination of meniscal allografts and polymer scaffolds could improve meniscal regeneration. They observed how reinforced polyglycolic acid (PGA) meniscal scaffolds reacted to cell seeding *in vitro*. The implants were subsequently implanted in New Zealand white rabbits for 36 weeks. They reported that the shape of the scaffold was maintained throughout the duration of implantation, attributed to the reinforcement of the PGA, which resulted in an increase in the compressive modulus by 28 times. They also observed regeneration of fibrocartilage, with an abundance of pretoeglycans, where the presence of collagen in implanted and non-implanted joints was consistent.

The PCU medial meniscus implant (NUsurface® Meniscus Implant, Active Implants Corp.) is a composite elastomeric implant composed of PCU, reinforced circumferentially by UHMWPE. The aim of the matrix is to redistribute the joint loads, while reducing the contact pressure by allowing local material deformation, whilst using the reinforcement to restrain the flow of the elastomer and allow high hoop stresses. The form of the shape was developed to match the shape of the existing cartilaginous surfaces and to fill the joint spaces through magnetic resonance imaging (MRI) (Elsner et al., 2010b). An additional requirement that was considered with this implant included ease of insertion, while allowing the possibility of future joint replacement if needed by not drilling into the bone. *In vitro* investigations on the biomechanical behaviour of the implant on human cadaveric knees were conducted by Linder-Ganz et al. (2010) and Shemesh et al. (2014). The meniscus of the cadavers were removed before implantation, and the investigations were done under compression which was representative of the maximum physiological load attained during gait. The contact pressure distributions on the tibial plateau underneath the implant were found to be similar to the natural knee, suggesting that the PCU implant fulfilled the role of load distribution. Subsequent tests conducted by Shemesh et al. (2014) of static soaking in simulated physiological fluid for 6 months, followed by dynamic fatigue loading of 2 million cycles, showed a slight increase in the implant's width and length around 1 µm, with moderate creep observed. The authors considered the latter effect to be advantageous as this suggested that the implant could conform to changes in the joint morphology, while improving stress distribution. Dynamic fatigue testing described by Elsner et al. (2017) was performed in a knee dynamic simulator for 5 million cycles. The average wear rate was lower than 20 mg/Mc, where the majority of the wear originated during the first 3 million cycles. The creep of the meniscus over time could be the reason for the transient behaviour observed, attributed to an improved lubrication regime. Zur et al. (2011) studied the chondroprotective effects of a variant of the NUsurface Implant (Figure 3 (b)) which was inserted in ewes (female sheep). The implant was composed of (PCU) which was reinforced circumferentially by high modulus Kevlar fibres. The study was conducted on six adult ewes, where the right joint of each ewe served as a control. The material properties and wear response of the implants remained stable after the retention period. Even though histological analysis revealed that there was a slight decrease in the proteoglycan content and cartilage structure, the overall osteoarthritis score (using the Mankin score which is a dedicated evaluation criteria utilised to assess the degree of osteoarthritis) was not different between the control and implanted joints at 3 and 6 months post-surgery. Currently the NUsurface Meniscus Implant is undergoing clinical investigation in the USA, with some promising results, however it is still not approved by the United States Food and Drug Administration (FDA).

An initial study of PCU meniscal implants (Figure 3 (c)) in a goat model were investigated by A. C. Vrancken et al. (2015). However, this implant failed mechanically when the suture came apart in the goat knees during the three-month implantation period. A second study by A. C. T. Vrancken et al. (2017) had the objective of improving the fixation method which failed in the first study by utilising a modified Revo knot, while increasing the implantation period to 12 months. This study also investigated the chondroprotective effect of the implant with respect to control groups comprising of state-of-the-art meniscal allografts, total meniscectomy and a control intact meniscus (6 animals per group). Interestingly, the second study also failed mechanically since the integrity of one of the implants was lost due to a complete tear at the posterior horn extension. Also, in some of the animals, the knot was observed to be partially or totally pulled out of the trans-tibial tunnel, exposing the cartilage. In both studies degenerative changes in the central tibial cartilage was observed across all animals, including the non-operated controls. However, cartilage histopatological conditions were similar across all implants and controls, suggesting that the device was successful in offering sufficient chondroprotection in goat knees with respect to the meniscectomised knee. Additionally, the PCU implant did not exhibit any additional material loss from the 3-month study (A. C. Vrancken et al., 2015), attributed to the nonlinear compressive creep behaviour of the material. A. C. T. Vrancken et al. (2017) hypothesise that the maximum compression of the posterior horn was reached upon 3 months.

4 Conclusions

In this review paper, elastomers used in the development of long-term orthopaedic implants were discussed. Silicones, polyurethanes and hydrogels and their properties were discussed for possible biomedical implantation. Subsequently, the application of these elastomers as orthopaedic implants were reviewed. The following conclusions may be drawn from this review:

- Elastomers including silicone, polyurethane and hydrogels are being investigated as possible material candidates in the development of orthopaedic implants. The combination of their mechanical and biomaterial properties give them a unique edge for possible application in this sector.
- A case study on a PCU acetabular implant utilised in a hip joint replacement revealed that the properties of the elastomer were integral to the behaviour of the implant. Excellent tribological and histological behaviour led to very low revision rates.
- Current studies on meniscal implants lead to the conclusion that although a leap in the development of these implants was observed, long-term studies in animal models still needs to be conducted to ascertain an adequate result on the long-term performance that such implants have on the knee-joint.

Acknowledgements

Research on elastomeric orthopaedic implantable devices is being conducted by the University of Malta in conjunction with the industrial partner Empav Engineering Ltd, and is being financed by the Malta Council for Science and Technology (MCST), through the Fusion R&I Technology Development Programme (MALTAKnee R&I-2019-027-T).

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XJENZA ONLINE
VOLUME 10 ISSUE 1, 2022

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